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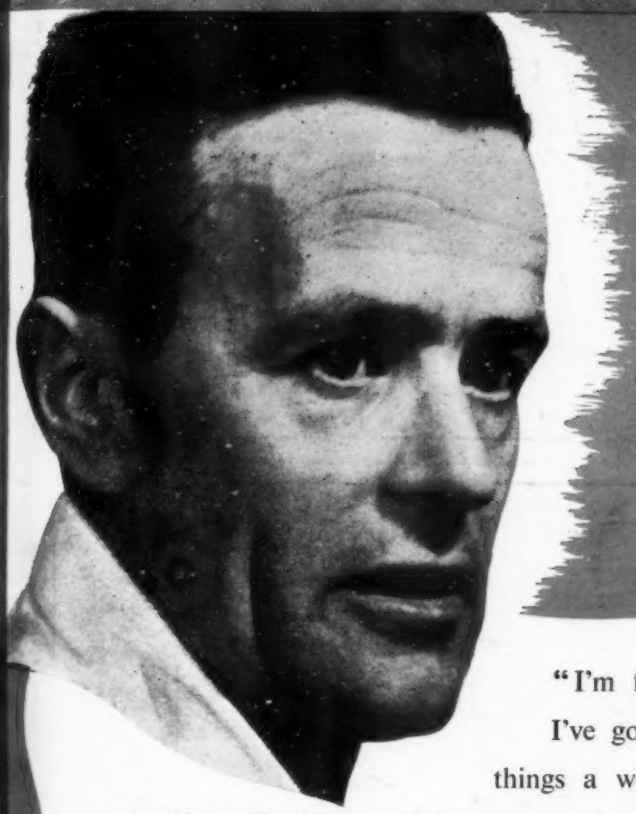
# METALLURGIA

## THE BRITISH JOURNAL OF METALS



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# METALLURGIA

## *The British Journal of Metals*

(INCORPORATING THE METALLURGICAL ENGINEER)


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METALLURGIA

THE BRITISH JOURNAL OF METALS.
INCORPORATING "THE METALLURGICAL ENGINEER."

JUNE, 1944 VOL. XXX. No. 176

# The Foundry Technical Man

AT irregular intervals since the end of the last war emphasis has been given to the need for educational facilities to permit apprentices and young journeymen in the foundry to obtain qualifications directly associated with work in the foundry. A further effort in this direction was made by Mr. Gardom in his presidential address at the recent annual meeting of the Institute of British Foundrymen, in which he directed particular attention to the foundry technical man.

Despite the apparent lack of educational facilities, there can be no doubt that considerable technical progress has been made in the foundry in recent years, from which it may be assumed that a reasonable proportion of those who enter the industry acquire the ability to effect improvements. That those at present in the industry are responsible for recent progress in both operating technique and in improving the properties of castings will be generally admitted, but, it is true, as Mr. Gardom says, that up to the present there is in this country no standard course of part-time study which can be followed by a man interested in the technical aspect of founding, and no recognised examination which can be taken as proof of ability and knowledge. An external degree or the entrance examination of one of the chemical or engineering institutions is often chosen, but the qualification gained can be no real guide to a man's technical ability to produce castings.

There has long been a need for special courses of instruction followed by examinations which would entitle the successful entrants to be recognised as qualified foundrymen. Indeed, a letter on the subject by the present writer was published in a contemporary journal about twenty years ago. Efforts have been made over a long period, but through lack of interest or support in one form or another, they have failed. Whether the enthusiasm and energy of Mr. Gardom can promote the institution of a reliable scheme to give effect to such a course remains to be seen, certainly all who are concerned about the future of the foundry industry will be behind him in his efforts.

Apart from the attention given by the Institute of British Foundrymen to education and training and methods of bringing youth into the industry, something more is needed to raise the status of first-class men in the industry, and Mr. Gardom suggests the establishment of a technical diploma. To obtain such a diploma entrants would need to show not only knowledge of foundry subjects, but also that they had satisfactorily filled a works' position for two or three years. The conditions would be so arranged that men possessing a degree would be required to fulfil the examiners' requirements in practical application while the practical man would have to demonstrate his knowledge of the theory. The institution of such a diploma offers a basis upon which to build competitive examinations which would allow men to develop their full powers after leaving school or after works' experience to obtain recognised qualifications of their ability. It is noteworthy that Mr. Gardom includes an oral and a practical examination in his suggestion, and considers that this could be undertaken by the newly constituted Technical Council.

In some sections of industry, as in the Civil Service, in the Navy, Army and Air Force, fitness for promotion has to be proved; yet in the foundry the obsolete method of recommendation still obtains. Men who have a veneer of polish talk themselves into good positions, and others who can get that repugnant thing "influence," find that mediocre ability is as good as genius. The illiterate foreman is not as common as he was twenty years ago, but there are a good many foremen yet lacking not only in technical knowledge, but in elementary education.

The qualities necessary in a responsible authority in the foundry are not easy to assess. Some are first-class craftsmen—or, as Mr. Gardom prefers, artisans—but quite incapable of organising men. Others, who are inferior craftsmen, are born organisers, and the exception is the man who is both a good craftsman and a good organiser. It may be admitted that it is not altogether a question of ability. Here, as elsewhere, the average man who qualifies himself by persistent study and endeavour is often more valuable than the outstanding man of talent who lacks energy or determination. The whole solution of the problem is that a standard of excellence should be insisted upon for all who aspire to leading positions in the foundry, and the only way to guarantee the maintenance of this standard is by open competitive examinations, and it is hoped that Mr. Gardom will press his suggestion with all the energy and determination at his command, and that the members of the Institute of British Foundrymen will give him all possible support in his efforts.

The subjects of an examination to obtain the diploma suggested cannot be discussed here, they can only be determined after very careful consideration by an authoritative body, such as the Technical Council of the above Institute. There would be certain obligatory subjects, and others would be optional. In addition to a technical knowledge and a proof of practical ability, papers should be included on such subjects as foundry management and the control and training of apprentices. The importance of a knowledge

**The fact that goods made of raw materials in short supply owing to war conditions are advertised in "Metallurgia" should not be taken as an indication that they are necessarily available for export.**

of estimating and of costs would doubtless find a place, as too much knowledge of all sections of the industry cannot be acquired by those in authority.

A standard of attainment cannot satisfactorily be set up by any one technical college or university, since there is no standard of technical education in the country that is quite uniform ; the matter ought therefore to be taken in hand by such a body as the Institute of British Foundrymen. From Mr. Gardom's address, the writer formed the opinion that the way should be open for every lad, however humble, to reach positions of authority in the foundry industry, if he has intelligence and grit. If we would thus democratise the industry we would have no need to fear the future. The one thing necessary is to get rid of passengers, whatever the position they hold in the industry, and the only way this can be done fairly and honestly is to equalise opportunity for acquiring a qualification recognising a definite standard of attainment in the theory and practice of founding. Whether it be called a technical diploma, foundry degree, or any other name matters little, provided that any who attain the required standard can be regarded and known as qualified foundrymen.

# Permeable Refractories in Gas-Fired Furnaces

IN our last issue we directed attention to the use of permeable refractories as linings of furnaces and to the technique developed in applying such linings for the more efficient use of fuel. The discovery of a new principle in furnace design is a rare occurrence. A furnace heated by the combustion of gases has always been held to comprise a combustion chamber, a chamber in which a charge is heated, and a flue through which the products of combustion are removed from the furnace ; some or all of these functions may be performed by the same chamber, but in general these functions are clearly defined. The last occasion when a new technique was introduced was in 1906-10, when Prof. W. A. Bone and C. D. M'Court developed the technique of surface combustion.

The new principle, full size experimental work on which was briefly described in our last issue, involves the use of permeable refractories through which furnace gases are withdrawn from the furnace chamber. It has been developed by the Department of Coal Gas and Fuel Industries at Leeds University, the Yorkshire Industrial Gas Development Centres, the Bradford Gas Department, and certain manufacturers, including a prominent manufacturer of insulating firebricks. The principle can be applied to many types of furnaces, and several units have been in normal productive operation for considerable periods. Although developed primarily with town gas as fuel, it is apparent that it could be applied with other fuel gases, provided that they are free from dust.

Among the characteristics of the newer insulating refractories, that are now employed in hot-face insulation, is that of high permeability to gas flow. This has been regarded hitherto as a difficulty overcome by backing the insulating refractory with a normal refractory of low permeability ; however, the idea was conceived that the gases could be withdrawn from the furnace chamber through the pores of the refractory, if it were made sufficiently permeable, and that considerable benefits would result. Data obtained in industrial installations employing this principle have given practical evidence of the benefits obtained, especially in the saving of fuel.

In addition to its possibilities in saving fuel, however, this new principle in furnace design offers possibilities for more uniform heating of furnace chambers. In the conventional design of furnace, where gases are burnt at one place and the products of combustion leave at another, it is difficult to overcome inequalities in temperature, and dead spots, where the gases do not circulate, are almost unavoidable. The application of the permeable refractory lining makes it possible to operate a furnace with a positive pressure throughout the furnace chamber and to withdraw the gases uniformly over the whole surface, so that the furnace chamber can be filled with flame.

As has been mentioned, several furnaces to which this new principle is applied have been in industrial operation for some time. The results fully bear out the deductions drawn from theoretical considerations, and the behaviour of these furnaces has been highly satisfactory. As a result of considerable experience, the conclusions so far reached indicate that with lower furnace temperatures, such as 500° C., the permeable wall construction will save about 10% of the fuel. With higher temperatures of, say, 1,400° C., the savings are likely to be near 40%.

At present the maximum suitable temperature is about 1,300° C., on acc uut of the limitations of the refractories. Again, because of the properties of permeable refractories, the principle is not of universal application—for instance, these refractories are not resistant to fluxes and could not be used for direct melting, nor are they recommended for forging furnaces, since the iron oxide scale would be troublesome. There are, however, a large number of processes conducted between 500° and 1,300° C. which appear to offer a wide field for immediate development.

## The Emergency Services Organisation of The Ministry of Aircraft Production

RECENTLY the Ministry of Aircraft Production has been concerned at the delays in informing the appropriate authorities of damage which has been sustained, through enemy action, civil fire, explosion, or accident, in the works of firms engaged in production for the Admiralty, Ministry of Supply and Ministry of Aircraft Production.

As many readers will be aware, the Emergency Services Organisation of the Ministry of Aircraft Production, through the medium of its local Reconstruction Panels, is responsible for facilitating the restoration of production following damage from such causes, but the attention of all member firms, engaged in war production, is drawn to the necessity of immediately reporting such damage to the local Reconstruction Panel of the Emergency Services Organisation. These Panels, which exist in every individual area in Great Britain and Northern Ireland, are able to render great assistance in facilitating the restoration of production.

If member firms are not acquainted with the address of their appropriate panel, such information will be sent on application to the Emergency Services Organisation, Ministry of Aircraft Production, Millbank, London, S.W. 1.

# Pure Oxide Refractories

By D. Kirby, B.Sc., F.R.I.C.

*Appreciable developments have taken place in the commercial production of pure oxide refractories in this country in recent years, especially in the attainment of high degrees of purity, very thin-walled shapes, and improved finish. Apart from alumina-ware, the bulk of the oxide ware came from Germany before the war and the demand for increased supplies has led to considerable progress in manufacturing technique. Various kinds of pure oxide refractories are discussed and particulars given of their applications and properties.*

THE term "refractory" implies difficult to fuse, but the popular conception of a high-temperature refractory material implies materials possessing not only high melting points, but mechanical strength and chemical inertness at high temperatures. While impervious mullite refractories are available for use up to 1,700° C., the materials which can be classified as refractory at temperatures above 1,700° C., are extremely limited. Furthermore, many of these materials, such as graphite, high melting-point metals—e.g., molybdenum (m.p. 2,450° C.) and tungsten (m.p. 3,400° C.), or metallic carbides, such as silicon carbide, tungsten carbide, and tantalum carbide—are by reason of their chemical properties unsuitable, in many cases, for use as high-temperature refractories.

With the possible exception of a few substances, such as the nitrides of boron or magnesium, the selection of a refractory for temperatures above 1,700° C. is limited almost entirely to one of the refractory oxides, such as alumina, magnesia, lime, beryllia, thoria, ceria, yttria, zirconia, or compounds such as spinels, or zircon. Due to ready hydration by absorption of water and carbon dioxide, lime is comparatively unstable, and hence is rarely used as a refractory except as a constituent of dolomite in steel furnaces. The refractory oxides possess little or no plastic properties, and consequently the preparation of ware presents considerable difficulty due to the essential absence of clay types of bond, and the high temperature treatment which is necessary if their true properties are to be developed.

The bulk of the supplies of commercially manufactured oxide ware other than alumina (excluding sparking plug insulators) used in this country pre-war, came from Germany, and these articles were in general particularly thin walled, and of pleasing appearance. In view of the increased demand for such ware, appreciable developments have taken place in the commercial production of pure oxide refractories in Great Britain in recent years, more particularly from the point of view of attaining high degrees of chemical purity, very thin-walled larger shapes, and improved finish.

The manufacturing difficulties with pure oxide refractories have been overcome by the development of new mixings and manufacturing technique under laboratory control, together with the installation of particularly high-temperature kilning facilities. The electrically fused oxides generally contain larger proportions of impurities than the c.p. or "chemically pure" variety, and consequently high-temperature calcination is frequently to be preferred to the electrical fusion of the grogs. The type of manufacture depends somewhat on whether porous or impermeable ware is required. Thus porous ware may be produced from oxides either electrically fused or calcined near the melting-point, while the impermeable oxide ware is generally manufactured by recrystallisation at high temperatures.

These pure oxides are characterised by particularly high softening and melting points, although in certain instances the presence of small percentages of particular impurities considerably reduces the softening point. This factor, together with the effect of different atmospheres and conditions on melting points, has resulted in different experimenters putting forward somewhat different melting-point values.

In general, the outstanding properties of these pure oxides are mechanical strength, physical stability, comparative inertness to hydrogen, nitrogen, cracked ammonia and carbonaceous or sulphurous atmospheres, electrical resistivity at high temperatures, exceptional resistance to the disintegrating action of carbon deposition in the case of porous ware, and resistance to corrosion and erosion.

Recrystallised ware is impervious, highly translucent, very hard and resistant to abrasion, has high mechanical strength, is of pleasing appearance, and is generally very useful for high temperature work, particularly under special atmospheres or high vacua.

The particular chemical characteristic of an oxide controls the special chemical properties of the articles made from it, so that they are particularly valuable for avoiding specific metal "pick-up" by the melt and have been employed successfully for melting pure iron and iron alloys, silicon, nickel, platinum and platinum-rhodium alloys. The smooth surface of recrystallised ware enables ingots with smooth outer surface to be obtained. In fact, in the case of crucibles with a satisfactory taper, the metal can frequently be allowed to solidify in the crucible without fracture, and the smooth internal surface allows removal of the ingot and re-use of the crucible.

Particular characteristic properties possessed by the individual oxides are considered later.

## General Applications

The applications of pure oxide refractories are already widespread, and this article necessitates brief reference only to some of their uses. Moreover, applications of a confidential nature appertaining to the war efforts are excluded.

**Fig. 1.—Miscellaneous fused alumina ware.**

Porous ware in the form of bricks, tubes, muffles, crucibles, boats and other containers, is useful for miscellaneous applications, including precious metal-melting, ceramics, and the associated metallurgical industry (particularly radio and powder metallurgy). In the glass industry pure oxide containers are useful for the laboratory testing or development of special glasses.

Impermeable ware is applied in the form of thermocouple insulators and sheaths for platinum-rhodium and tungsten-molybdenum thermocouples ; plain or flanged pyrometers ; combustion and miscellaneous furnace tubes, including induction furnace tubes ; externally or internally grooved furnace tubes for platinum, molybdenum or tungsten winding, operating in some cases under vacuum or specially protective atmospheres for metallurgical research and development.

The highly translucent recrystallised ware is particularly useful for research work in the form of dishes, crucibles, plain or grooved muffles, boats, miscellaneous electric furnace shapes, stirrers, grinding balls, pestles and mortars, tiles and miscellaneous components of the wireless industry.

Products manufactured from the oxides are not restricted to high-temperature work. In view of their special chemical properties, they are suitable for low-temperature work which has previously been carried out in platinum, silver or porcelain vessels. An outstanding development of recrystallised pure oxides, such as alumina, thoria, magnesia, zirconia, is ware of eggshell thickness, by means of which the risk of fracture under temperature gradients, such as is experienced under high-frequency melting conditions has been minimised.

Before considering the various refractory oxides individually, it should be indicated that widely different values have been reported by observers for the physical characteristics of pure oxide refractories, more particularly electrical resistivity, coefficient of thermal expansion, thermal conductivity, etc. This is explained by the variation with temperature, differences in chemical purity, grain sizes and grading, and the thermal history of the test specimens, and the fact that the determinations of many of these physical characteristics are not easy, particularly at high temperature.

*Alumina.*—Ware available in this oxide may be either porous or impermeable.

## Fused Alumina

Porous ware is generally made from fused alumina (alpha alumina or corundum) and has a melting-point of 2,050° C., S.G. 3·9 coefficient of thermal expansion $8{\cdot}5 \times 10^{-6}$, high electrical resistivity particularly at high temperatures, and high resistance to abrasion. Its capacity for resisting temperature gradients has been appreciably increased by the production of thin-walled translucent ware. Chemically, it is a slightly acid refractory, and in a pure state is unaffected by reducing gases, such as carbon monoxide and hydrogen up to temperatures approaching its application limit.

Fused alumina ware is used in the form of miscellaneous moulded, cast or machine-made shapes—e.g., for lining high-temperature electrical or gas-fired furnaces for use up to 1,900° C.

Plain or externally or internally grooved one-piece or sectional muffles are wound with tungsten and molybdenum strip for electric furnaces operating under hydrogen or cracked ammonia atmospheres—e.g., swageing and wire drawing ; sintering and degasing of wireless valve filaments ; sintering of metallic carbides. Platinum wound fused alumina furnaces are employed for miscellaneous laboratory applications at intermediate temperatures, including carbon and sulphur determinations on ferrous alloys. Further applications of fused alumina

TABLE I.

COMPARISON BETWEEN PHYSICAL PROPERTIES OF SOME REFRACTORY OXIDES.

| Refractory. | Formula. | M.P. | Limit of Application. | Hardness Mohr Scale. | S.G. | S.H.* | Linear Coefficient of Expansion, 25°–800° C. |
|---|---|---|---|---|---|---|---|
| Alumina..... | $Al_2O_3$ | 2,050° C. | 1,950° C. | 9·0 | 3·9 | 0·20 | $8{\cdot}5 = 10^{-6}$ |
| Magnesia ... | MgO | 2,800° C. | 2,400° C. | 6·0 | 3·7 | 0·23 | 13·5 |
| Beryllia ..... | BeO | 2,570° C. | 2,400° C. | 9·0 | 3·0 | 0·29 | 7·5 |
| Zirconia ..... | $ZrO_2$ | 2,700° C. | 2,500° C. | 6·0 | 5·7 | 0·15 | 6·5 |
| Thoria..... | $ThO_2$ | 3,050° C. | 2,700° C. | — | 9·7 | 0·06 | 9·5 |
| Lime ..... | CaO | 2,570° C. | 2,400° C. | — | — | — | — |
| Silica ..... | $SiO_2$ | 1,710° C. | 1,680° C. | 7·0 | (2·2–2·6) | 0·18 | (varies with temp. inversion) |
| Zircon ..... | $ZrO_2$ $SiO_2$ | Decomposes above 1,900° C. | 1,750° C. | 7·5 | 4·7 | 0·13 | 4·5 |
| Spinel ..... | $Al_2O_3$ MgO | 2,130° C. | 1,900° C. | 8·0 | 3·6 | 0·20 | 8·5 |
| Mullite ..... | $3Al_2O_3$ $2SiO^2$ | 1,810° C. | 1,700° C. | — | 3·0 | 0·17 | 5·5 |
| Sillimanite .. | $Al_2O_3$ $SiO_2$ | 1,810° C. | 1,700° C. | 7·5 | 3·2 | 0·17 | — |

ware take the form of crucibles, boats, sighting sheaths, etc.

While fused alumina ware has been available for some years, an improved grade is now obtainable, having 99·8% alumina content, providing increased volume stability, increased hot strength, higher electrical resistivity and increased resistance to abrasion. In the case of hollow-ware, improved resistance to temperature gradients is obtained with the thin-walled ware used down to $\frac{1}{16}$ in. wall thickness.

The translucent form of chemically pure fused alumina is employed in the production of jewel bearings in some types of scientific instrument manufacture.

### Recrystallised Alumina (Impermeable)

Generally speaking, this is a purer form of alumina than the fused grade, since it may be produced from material of 99·98% alumina content. Physically, recrystallised alumina is gas-tight, has higher mechanical strength, is extremely hard (9 Mohr) and resistant to abrasion, specific gravity 3·9, specific heat 0·2, high thermal conductivity, thermal expansion increasing with temperature from 5 to 8 $\times$ $10^{-6}$ between 20° and 800° C., high electrical resistivity at high temperatures (higher than quartz, glass or porcelain). The resistance of the material to temperature change is high in view of its high density, but it is desirable to use thin-walled ware wherever possible.

Chemically, the material is a slightly acid refractory suitable for many acid and alkaline fusions. It is highly resistant to carbon monoxide, carbon dioxide, hydrogen and chlorine at particularly high temperatures and superheated steam.

Recrystallised alumina ware is highly translucent and of particularly pleasing appearance, especially in the case of ware approaching egg-shell thickness. Such ware is finding applications for chemical apparatus, since, when handled with care, it serves many of the functions of platinum ware at smaller cost, for use in analytical and manufacturing processes for ceramic and metallurgical industries, rare metal assay, etc.

Various shapes are available for users' requirements, varying from micro-combustion boats of 0·5 ccs. capacity, to crucibles of capacity up to 2 litres. Thin-walled crucibles in recrystallised alumina are useful for induction furnace melting of certain metals, oxides, glasses and slags, particularly under certain vacuum conditions and where contamination from the container may be detrimental.

Recrystallised alumina single-bore or multi-bore insulating tubes are advantageous for insulating platinum or platinum-rhodium thermocouples, more essentially where conditions may be reducing, thereby avoiding the formation of silicides which would impair the E.M.F. characteristics of the thermocouple.

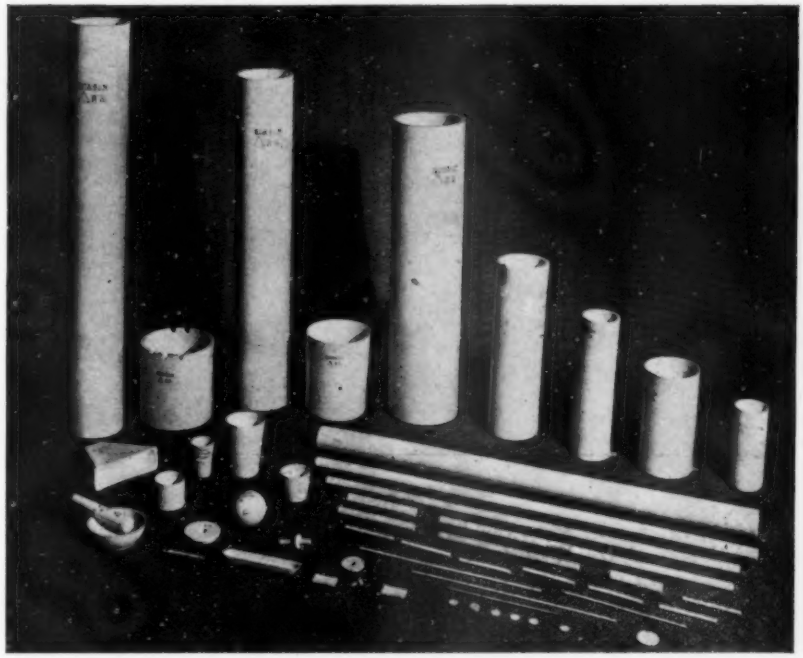

**Fig. 2.—Miscellaneous recrystallised alumina ware.**

While porous sighting sheaths may be employed with radiation pyrometers, suction or thermo-electric pyrometers necessitate the use of impervious sheaths in the form of recrystallised alumina or mullite for protecting the couple wires against vapours and reducing conditions, while they also offer protection against mechanical fracture. Tubes in recrystallised alumina are useful for high-temperature research under special atmospheres, and plain or grooved tubes up to 24 in. length with $2\frac{1}{2}$ in. bore have been successfully employed for temperatures approaching the limits for alumina ware. Due to its hardness and high resistance to abrasion, recrystallised alumina is used for thread guides, spray nozzles, grinding balls, laboratory pestles and mortars, etc. Probably its widest use is in the form of sparking plug insulators which require considerable electrical breakdown resistance at moderately high temperatures, good thermal conductivity and capacity for resisting the detrimental effect of carbon or lead deposition.

### Beryllia

Beryllium oxide has been generally available only during the last 10 years in conjunction with the increasing uses of beryllium alloys, while the highly purified form of beryllium oxide, 99·8% purity, has been marketed only during the last seven years. The principle types of ware available are high-temperature fired volume stable material or the recrystallised material.

This oxide possesses outstanding characteristics as a refractory, particularly for high-temperature work up to 2,400° C., due to its chemical inertness, and there is little doubt that its present applications would be more widespread but for the fact that supplies are only available for high priority work during the war period.

Beryllia melts at 2,570° C., but other oxides—e.g., alumina, magnesia, etc., readily form fusible slags with

Fig. 3.—Miscellaneous beryllia ware.

beryllia at high temperatures. The material has higher strength than the other oxides under similar conditions, higher thermal conductivity than alumina and zircon, a hardness of 9 (Mohr), specific gravity 3, specific heat 0·29, and thermal expansion $7{\cdot}5 \times 10^{-6}$ up to 1,000° C.

Beryllium oxide refractories show distinctive advantages over alumina, due to the 500° C. higher melting point, constant physical properties over almost a thousand degrees above 1,500° C., higher thermal conductivity, greater insensitivity to sharp temperature changes, so that they are suitable for high-frequency furnace melting under oxidising or vacuum conditions. The higher electrical resistivity at high temperatures makes the material particularly valuable for tungsten-wound furnaces operating up to 2,350° C.

The higher resistance of beryllia to reaction with carbon and carbonaceous vapours at high temperatures is a desirable property, enabling the material to be used as radiation shields for carbon crucibles at high temperatures, and as containers in Hirsch and Tamman furnaces. The low vapour pressure of beryllium oxide up to 1,900° C. ensures its usefulness for high-temperature vacuum work.

Beryllia crucibles have been used for melting pure beryllium metal and pure platinum in vacuum induction furnaces. Ware approaching egg-shell thickness with a particularly smooth, glazed surface, has been developed, thus meeting difficult temperature conditions where purity is essential.

Porous ware has been successfully used as crucibles, boats, sighting sheaths, electrically wound furnace tubes, Hirsch furnace tubes for use up to 2,350° C. and miscellaneous applications which cannot be enumerated under present war time conditions.

## Magnesia

Magnesium oxide may be obtained in a variety of physical grades, but the ware is normally marketed either as electrically fused, recrystallised or high-temperature sintered ware. The pure oxide does not melt below 2,800° C., but this figure is considerably influenced by the presence of impurities. The material has a high thermal expansion ($13{\cdot}5 \times 10^{-6}$) up to 1,800° C., but this is offset by its high thermal conductivity (0·0047 C.G.S. units) for resisting temperature gradients. Its specific gravity is 3·7 (B magnesia or periclase) and hardness 6 (Mohr).

The oxide is a highly basic refractory and is consequently useful for contact with basic melts, more particularly the entirely clay-free magnesia crucibles in fused or recrystallised grades which are used down to $\frac{1}{16}$ in. thickness in section.

The tendency towards hydration and susceptibility to attack by dilute acids is greater in the case of the more lightly calcined grades, but smaller in the case of the high-temperature fired or fused grades.

Fused magnesia is stable in contact with carbon up to 1,800° C., but some reduction occurs at higher temperatures with increase in volatility. Magnesia is considered to dissociate *in vacuo* at temperatures of the order of 1,800° C., and the material is free from volatility under oxidising or neutral conditions up to 1,800° C., but exerts measurable vapour pressure at 2,000° C.

Fused magnesia is employed for electrical elements in view of its high electrical resistivity, as furnace linings for miscellaneous basic high-frequency induction furnaces and in Tamman and Arsem furnaces. In the precious metal industry it is suitable for assaying, while sintered magnesia crucibles are recommended for miscellaneous metallurgical melting operations—e.g., the melting of alloys containing vanadium, molybdenum and tungsten.

## Thoria

Thorium oxide has the highest melting point of all the refractory oxides (approximately 3,000° C.). It is characterised by particularly high density, and forms a useful refractory for resisting basic compounds at high temperatures. It possesses a high coefficient of expansion, so that products are affected by sudden temperature changes, although this may be offset by reduction in wall thickness to $\frac{1}{16}$ in. for small ware. Claims have been made for successful melting of platinum and iridium in this type of crucible.

## Zircon

This refractory has no definite melting point, but decomposes at approximately 1,900° C., and consequently is generally successfully used only up to about 1,750° C. It possesses a very low thermal expansion, and is consequently resistant to temperature gradients. It has a hardness of 7·5 (Mohr), true specific gravity 4·7, specific heat 0·13, thermal expansion $4{\cdot}5 \times 10^{-6}$ up to 1,400° C., and a thermal conductivity of 0·004 C.G.S. units.

Theoretically pure zircon contains 67% zirconium oxide and 33% silica, and this decidedly acid material is resistant to acid slags, but basic compounds affect it at high temperatures. Zircon is suitable for melting platinum and platinum-rhodium alloys in high-frequency induction furnaces under oxidising conditions, but not so under reducing conditions. Zircon frequently replaces

magnesium oxide in elements of electric heating appliances.

### Zirconia

The melting point of zirconium oxide is approximately 2,700° C. and ware may be used up to 2,500° C. It has a hardness of 6·5 (Mohr) true specific gravity of 5·5 to 6, specific heat of 0·15, and coefficient of thermal expansion 5·5 to 6·5 $\times$ $10^{-6}$.

In its pure form the material is particularly sensitive to temperature changes due to the presence of crystal inversions accompanied by volume changes at 1,000°–1,100° C. Addition of small quantities of other oxides has considerably reduced this inversion defect without appreciably lowering the refractoriness, thus permitting reasonably rapid heating and cooling. Zirconia is a basic refractory and is resistant to the action of basic slags and glasses at high temperatures for long periods.

This oxide is not reduced by hydrogen and has a high electrical resistivity in the pure form, but small quantities of impurities greatly increase its electrical conductivity. Zirconia crucibles have been successfully used for melting chemically pure chromium and platinum, and the refractory is receiving increasing attention for use in electric induction furnaces and electric heating appliances.

**Fig. 4.—Miscellaneous magnesia, thoria, zirconia and zircon ware.**

### Spinel

Magnesia-alumina-spinel resembles alumina in many respects, but is more neutral at high temperature than alumina, as the latter takes on the property of an acid. Spinel is more susceptible to changes of temperature than alumina, due to its low heat conductivity, and products made of recrystallised alumina are superior in hardness and mechanical strength.

### Post-war Applications

As a post-war development in the refractories industry, there is little doubt that pure oxide refractories will receive more widespread attention due to the tendency towards progressively higher temperatures with increased specialisation in refractories for specific applications.

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## Society of Instrument Technology

A SOCIETY with the above title has been formed for those interested in the design, manufacture, use and maintenance of scientific instruments. Its objects are :—

(*a*) The advancement of instrument technology by the dissemination and co-ordination of information relating to the design, application and maintenance of instruments.

(*b*) The provision of opportunities for discussion, particularly between the designers and manufacturers on the one side, and the users on the other.

(*c*) The provision of opportunities for discussion and collaboration between the Society and other associations.

(*d*) The encouragement of technical education for persons who wish to enter, or are already in, the industry dealing with instrument research, design, manufacture or use.

(*e*) The encouragement of research into problems relating to instrument technology.

(*f*) To encourage the standardisation of instruments and accessories by collaboration between manufacturers and users.

(*g*) The determination of a commonly acceptable terminology.

(*h*) Enhancing the status and prestige of those employed in the industry.

Members of Council and Officers are :—President : Sir G. P. Thomson, M.A., F.R.S. Members of Council : Dr. W. J. Clark, Mr. G. H. Farrington, Dr. W. F. Higgins, Mr. W. B. Wright, Mr. C. R. Sams, Mr. E. B. Moss, Mr. R. E. Iggledon, Mr. F. C. Knowles, Mr. D. A. Oliver, Dr. H. S. Gregory, Dr. E. Griffiths, Prof. F. Debenham. Hon. Treasurer : Dr. H. B. Cronshaw. Hon. Secretary. Mr. L. B. Lambert.

Those interested are invited to send their name and address to the hon. secretary, who will forward details of membership and an application form. The secretary's address is 55, Tudor Gardens, London, W. 3.

It is intended to call a general meeting, probably in the early autumn, at which the Constitution and Rules, as recommended by the Council, will be submitted for the formal approval of intending members.

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Mr. F. J. Shotton, managing director of Albion Drop Forgings, Ltd., has been appointed chairman of the company in succession to the late Mr. J. T. Brockhouse

# Fluorescence as an Aid to Inspection

By J. Brennan, B.Sc., Ph.D.

*The underlying phenomena of fluorescent materials in their application for inspection purposes are briefly described. Two methods of applying these materials for the detection of cracks, flaws, porosity and surface imperfections are discussed; one designed for laboratory use and the other for production uses. Methods of application are described.*

FLUORESCENCE is the emission of light by matter under the influence of an exciting agent, in nearly every case the radiation required to excite fluorescence is shorter in wave-length than the fluorescent light it produces. The fluorescent material acts as a transformer in much the same way as an electrical transformer—transforms energy from one voltage to another. A number of exciting agents are known, each suitable for a particular purpose in the same manner as electrical supply voltages are chosen for a particular use—the exciting agents include cathode rays, canal rays, X-rays, and ultra-violet light. We shall only deal with the latter, as it is easiest to produce and safest to use.

Ultra-violet or "black light," as it is commonly known, is radiation in that portion of the spectrum invisible to the human eye—it extends from the end of the visible violet spectrum with a wave-length of 3,900 A° to 2,537 A° (1 A° = $10^{-8}$ Cm). Radiation shorter than 3,600 A° though quite invisible is harmful to the skin and eyes, consequently a filter must be provided to isolate that portion of the spectrum, radiation between 3,900 A° and 3,650 A° has no harmful effects and is the most suitable range for inspection purposes.

The most readily available source of this harmless radiation is the black lamp. These lamps are available in two sizes, 80 and 125 watts, and can be used on any A.C. supply. This lamp comprises an inner quartz tube with thermionic electrodes in either end, and enclosed in an outer envelope of black glass.

When the lamp is switched on an arc is struck between the electrodes in the quartz tube which contains argon gas and a drop of mercury; in a few minutes the mercury is vapourised by the heat and the mercury vapour becomes the medium through which the arc is maintained. This arc has a negative resistance characteristic and a choke must be interposed in series with it and the mains in order to stabilise the arc.

The mercury arc produces radiation extending from the near infra-red to the far ultra-violet, including, of course, the entire visible spectrum. The black glass outer envelope prevents the passage of any portion of this spectrum other than the narrow band between 3,900 A° and 3,650 A° and a small portion of the red heat rays. These lamps are quite robust and have a normal life of some 1,500 hours.

Fluorescent materials convert this otherwise invisible radiation into visible light: this is due to the peculiar molecular structure of the fluorescent materials. A molecule of fluorescent material consists of atoms, combined in a bond which will give the greatest decrease of energy content for the system, each atom consists of a positively charged nucleus and electrons; the number of electrons is such that the atom is neutral and, moreover, the centre of gravity of the negative charge coincides with the positively charged nucleus.

Surrounding the nucleus are a number of orbits or shells occupied by electrons, each of which carries a unit charge; each electron is normally constrained to move in its particular orbit only. The passage of an electron from one orbit to another corresponds with the absorption or emission of energy.

When a fluorescent material is subjected to ultra-violet radiation, the energy of which is sufficient to force some of the electrons into an outer orbit of higher energy state and an unstable condition is set up; if the electron returns to its original position there is an emission of energy. Since some of the energy originally absorbed has been lost in the form of heat, the emitted unit has less energy than the one which entered; this means it has a lower frequency and is consequently nearer the red end of the spectrum than the absorbed radiation, thus the incoming rays are invisible and the emitted rays visible.

Fluorescence only occurs while the electron is returning to its normal energy level; if the electron can be retained in the excited state or another electron injected into the open shell fluorescence will not occur. This is known as inhibiting or quenching. As we have seen, an electron can be freed by absorption of light; it can also be freed by thermal energy; thus, if a fluorescent material is heated the electrons of the constituent atoms can be brought into a state when in the presence of an electron possessing greater affinity for the positively charged nucleus the open shell is filled and fluorescence is inhibited.

The major use of fluorescent materials for inspection is directed towards the detection of cracks, flaws, porosity, and surface imperfections in non-ferrous materials; there are two methods in general use, both of which I have been responsible for developing.

## Laboratory System

One system designed primarily for laboratory use comprises two tanks, one electrically heated and controlled to operate at temperatures up to 70° C. This tank contains either carbon tetrachloride or trichlorethylene, in which is dissolved a small quantity of a suitable fluorescent hydrocarbon. The other tank contains trichlorethylene or carbon tetrachloride, one of the higher homologues of benzene and a trace of an inhibitor.

The test procedure consists of immersing the part in the heated liquid for a few minutes, and dipping it while still warm into the cold or inhibitor tank; inhibitation takes place over the entire surface. When the specimen cools down, the presence of cracks, etc., will

be indicated by vivid blue green lines where the fluorescent material, trapped in the voids, has come to the surface and crystallised from the carrier.

This system is extremely satisfactory for small runs or testing a variety of specimens. As the tank only contains 2–3 gals. of solution, the wastage by contamination of the inhibitor bath is not serious; this contamination is caused by the fluorescent material carried over a specimen and in time reaches a stage where the inhibitor bath becomes fluorescent; the solvent can be distilled and used again, or treated to remove the fluorescent material.

### System Designed for Production Uses

The other system designed for production uses comprises one tank which runs at 75–80° C. the tank is fitted with a condenser which causes the vapour to reflux over the layer of liquid. The liquid is carbontetrachloride, to which is added methylcyclohexanol, a fluorescent material, and an inhibitor. The inhibitor is ineffective in solution in the presence of methylcyclohexanol, but is active in the vapour phase. The parts are loaded in trays and immersed in the liquid for 30–40 secs., and then held in the vapour for 25–30 secs. If the specimen is removed from the liquid without passing through the vapour, it will be found to be covered with a layer of yellow-green fluorescent material; immersion in the vapour completely quenches this overall fluorescence. The fluorescent material trapped in the cracks, blowholes, porous spots, etc., comes to the surface by capillary action. The first crop of crystals draw further quantities of the solvent from the voids to the surface, the capillary effect, which is a cumulative one in this instance, results in the complete removal of the solvent from the voids; since the solvent is extremely volatile and the crystals build up upon the surface, the greater the quantity of fluorescent material present the brighter the indication.

With this method no loss other than drag-out occurs, and there is no contamination problem, as the inhibitor action takes place in the vapour. Figures collected over a period of three months' actual operation show that the cost of testing non-ferrous castings having a surface area of 2·4 sq. ft. cost 0·054d. per sq. ft. in energy and fluorescent loss.

Both these methods give clear indications of the presence of cracks, flaws, voids, etc., which are open to the surface, but will obviously give no indication of internal flaws.

It has been found possible to interpolate roughly the relationship of the distance between the lamp and the specimen, and the brightness and depth of the crack. This can be found experimentally by spot-welding pieces of material and gapping them, as shown in Fig. 1.

The intensity of the indications on D will be less than on C, and so on. In this way a rough indication can be produced, if a crack $\frac{1}{32}$ in. is unimportant and can be machined out—D should be $\frac{1}{32}$ in., and the lamp raised a distance from the specimen, sufficient to give no indication. If C is $\frac{3}{64}$ in., it will give a clear indication, hence an inspection system of "go—no—go" can be used. The initial settings are obviously important, and should be checked at regular intervals.

Another application of fluorescent materials is fluorescent magnetic ink, which can be used on ferrous materials.

Fluorescent magnetic crack detection depends upon the fact that in a magnetic material with a crack or other fault the magnetic susceptibility of the fault is markedly inferior to that of the surrounding material. When the specimen is magnetised the fault causes the magnetic flux to bend around the fault, seeking an alternative path in the material surrounding it. If the fault is a small crack at the surface of the material, the field distortion is very local, while a larger internal crack will give a field distortion over a larger region. In any case, the distortion can be made appreciable beyond the surface of the article in the air surrounding it, by making the intensity of magnetisation high enough. It is the external field effect that makes fluorescent crack detection possible. If a specimen is magnetised and immersed in a solution which contains a suspicion of metallo-organic fluorescent material, with an extremely high magnetic susceptibility, the particles will tend to pile up on the surface over the crack by virtue of the

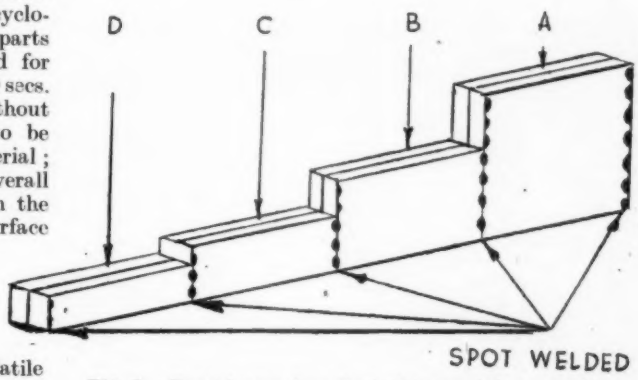



**Fig. 1.—Experimental method of determining, roughly, the relationship of the distance between the lamp and the specimen.**

distortion caused in the flux due to the fault; the degree of distortion will be a function of the depth and width of the crack, consequently a good indication of the seriousness or otherwise of the fault can be obtained from the material when it is subject to ultra-violet light, as the brightness of the indications is dependent upon the quantity of fluorescent material held on the surface.

When testing for cracks running more or less transversly to the length of the article under test, a magnetic flux can be established along the length of the article by making it form part of a closed iron circuit which is magnetised by wound coils of wire energised from the mains.

Another method is to pass the article through a current solenoid or coil using the phenomenon of residual magnetism, to cause the necessary flux.

For testing cracks running substantially parallel to the length of the article, such as laps, seams, etc, a large current is passed through the length of the article; this current produces concentric rings of magnetic flux at each point along the current flow, and at right angles to it, so causing the article to be magnetised in closed loops around its periphery. This effect takes place whether the current is passing directly through the article or through a conductor threaded through the specimen.

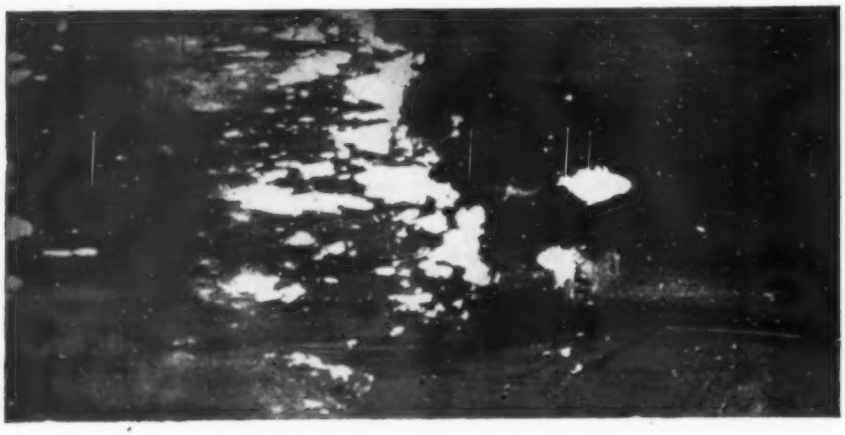


Fig. 2.—High spots under ultra-violet light.

Fig. 3.—Same plate as above under normal light, with mechanic's blue.

This method is simple to use, and leads to a reduction in the time required for inspection, as it is obviously easier to see the vivid indications against the purple background of the ultra violet light than an indefinite black line by normal lighting, which on black or oxidised components the improvement over existing methods is very apparent.

Where two surfaces must be brought to a state approaching optical flatness, the substitution of one of the metallo-organic materials in a suitable carrier for prussian blue has many advantages. Fig. 2 shows the high spots under ultra-violet light, and Fig. 3 the same plate under normal light, with mechanics blue; the difference in contrast is very clear. Metallo-organic material can also be used as indicators for bedding bearings, scraping lathe beds, etc. Closer tolerances can be obtained, as the hardness factor of the fluorescent material and the particle size is much smaller than any of the blue materials.

Permanent records of tool or gear-teeth profiles can be produced by saturating a fairly absorbent paper in a solution of a suitable fluorescent material in a volatile carrier and allowing the paper to dry. The profile is projected or contact printed upon the paper, using radiation in the neighbourhood of 3,650 A°. A profile image is formed which provides a permanent record when viewed under a black lamp.

This method may also be used for making out large surfaces direct from the tracing. Fluorescent material is sprayed upon the surface and the tracing applied; exposure for a few seconds to a suitable light source produces a clear replica which will withstand handling and normal shop usage. The time saving effected by this method is obvious when compared with normal marking-out methods.

Fluorescent materials are not the answer to all inspection problems. Experience over a period of three years, including intensive laboratory and field trials as well as the data accumulated from production installations, indicate that for crack detection such methods are valuable, saving both material and time, but, like all new methods, require in the first instance a scientific approach to decide the technique to be used on any particular type of material.

Where this has been perfected, the plant can be operated by unskilled personnel with a minimum of training and supervision, with the assurance that reproducible results can at all times be obtained.

## Hiduminium Applications, Ltd.

IN the post-war period light metals will undoubtedly play an indispensable part in solving the mechanical and structural problems which will be encountered. In order to assist their application so that they give the maximum service, a new company has been formed under the above name by High Duty Alloys, Ltd., Reynolds Tube Co., Ltd., and Reynolds Rolling Mills, Ltd. Its main object is to act as a consultant, to collaborate with designers and constructors in any industry in order to secure the best use of Hiduminium alloys. Those interested in further information are asked to write to Hiduminium Applications, Ltd., Farnham Road, Slough, Bucks.

The articles entitled "Weldable Hard Metals," "Wear Phenomena through Rubbing Friction without Lubrication," and "Finishing Processes Employing Abrasives," published in our last issue, were translations supplied by courtesy of the Research Department, Diamond Trading Co., Ltd., London, E.C. 1.

# Practical Aspects of Diffusion in Metals

*A symposium on the above subject was presented at a recent meeting of the American Institute of Mining and Metallurgical Engineers. It comprised an introduction to the subject by R. F. Mehl,* which was followed by a number of papers covering such aspects as the degassing of metals, diffusion in relation to changes in microstructure, the influence of gas-metal diffusion in Alclad sheet, diffusion of indium in bearings and diffusion in chromising. The main aspects discussed are summarised in this article.*

EXISTING knowledge with regard to diffusion was classified by Mehl, as a preface to a recent symposium on the subject, in which he considered the process of diffusion among liquid metals and the diffusion of gases in liquid or solid metals with particular reference to the rate of diffusion in both cases. Consideration was also given to the formation of thin films, and diffusion in solid metals was discussed with reference to the freezing of alloys, precipitation from solid solutions and eutectoid decomposition. Instances of the practical usefulness of diffusion considered included carburisation, decarburisation and nitriding, the operation of the process of diffusion in the fabrication and treatment of metals by cladding, and the protection of materials by metal coatings and films. The scientific knowledge of diffusion with regard to theories on the atomic mechanism of diffusion were also briefly discussed and suggestions made as to where new work might be most productive of useful results.

## The Degassing of Metals

The results obtained from a comprehensive study of the degassing of molybdenum in order to determine how rigorous a treatment was necessary to completely remove absorbed gases from molybdenum electrodes in vacuum tubes was dealt with by F. J. Norton and A. L. Marshall. Some work was also done with tungsten, nickel, iron and carbon. Tests were made with molybdenum from all commercial sources in a specially designed unit consisting of a degassing system and an analytical system. In carrying out the tests it was found necessary to heat molybdenum to 1,760° C. in a vacuum of the order of 0·001 micron for a time, which varied linearly with the thickness in order to obtain a condition in which no further gas was evolved by the sample.

The gases obtained from molybdenum were carbon monoxide and nitrogen, the nitrogen being the more difficult to remove. The oxygen was present in the gases and hydrogen was not a common constituent. No difference was found in the nature of the gases present, the total amounts evolved, or their ease of removal for different samples of molybdenum from various sources. The reason for this was apparent when a study was made of the manner in which gases were absorbed by gas-free molybdenum. It was also found that a sample of molybdenum once degassed remained degassed provided proper precautions were taken, the most important being to avoid handling. A sample, however properly degassed, could be handled and subsequently assembled in a tube and again degassed readily.

To degas tungsten at a rate comparable with that obtained with molybdenum at 1,800° C. it was necessary to heat to 2,300° C., and at 1,030° C. nickel had the same vapour pressure as molybdenum at 1,760° C., and this was the highest temperature at which nickel could be maintained for a long period in a high vacuum tube without noticeable evaporisation. Five types of iron, including a low carbon steel, two exceptionally pure commercial irons, and two cast steels were also investigated by a similar technique at temperatures ranging from 850° to 1,400° C. Varying percentages of carbon dioxide, carbon monoxide and nitrogen were obtained, and in some cases hydrogen, but no oxygen was evolved in any experiments. It was also found possible to degas anodes of Acheson graphite at 2,150° C., so that subsequent heating at higher temperatures gave no further gas, and it was found that the gas evolved in the range 1,700° to 2,200° C. was predominantly nitrogen.

## Diffusion and Microstructure

Diffusion in relation to changes in microstructure was discussed by M. L. V. Gayler, who showed that diffusion in metals and alloys is a process without which little use could be made of much available material. Without diffusion taking place in the liquid state, no castings could be made, and it is therefore the most important factor affecting the structure of metals and alloys. The rate of diffusion depends on three main factors: (1) Temperature; (2) concentration gradient; and (3) activation energy. The growth of grains and particles in the solid alloy also depends on these factors and are therefore intimately associated with diffusion. The rate of homogeneisation in a cast alloy depends on several

TABLE I.
ANNEALING FOLLOWED BY HOT WORKING (GAYLER).

| — | 1 in. Diameter as Cast. | 1 in. Diameter as Cast, Annealed 37 Hours at 505° C. | 3 in. Diameter Billets Annealed 37 Hours at 505° C. then Hot Pressed at 550° C. Down to 1 in. Diameter. |
|---|---|---|---|
| 1% Cu, 3% Mg, Al remain. | | | |
| Tensile strength | 7 | 12 | 15 |
| Elongation | 4 | 7 | 24 |
| 1% Cu, 3% Mg, 5% Ni, Al remain. | | | |
| Tensile strength | 7 | 9 | 17 |
| Elongation | 1 | 1 | 18 |
| 1% Cu, 3% Mg, 10% Ni, Al remain. | | | |
| Tensile strength | 9 | 10 | 16 |
| Elongation | 0·5–1 | 0 | 9 |

* *Metals Technology*, 1944, vol. 11, No. 1, A.I.M.M.E. Technical Publications 1638, 1643, 1648, 1645, 1659, 1640, and Abstract.

factors, such as: (1) Rate of solidification, which involves grain and particle size which, in their turn, depend on diffusion; (2) the nature of the constituents; and (3) the temperature interval between the melting point of the metal or alloy and the temperature at which it is being heat-treated. Rapid diffusion can be brought about by the following general methods: (1) Suitable annealing; (2) hot-working; and (3) cold-working followed by heat-treatment. The data in Table I also show that by annealing—i.e., by the acceleration of the rate of diffusion—it is possible to hot-work a cast alloy and thus improve its mechanical properties.

### Gas-Metal Diffusion in Fabricating Processes

A brief survey of the ways in which gas-metal diffusion serves and obstructs the purposes of the metal fabricating industries was dealt with by F. N. Rhines as a result of consultation with more than thirty-six practicing experts. The nature of gas-metal diffusion is first discussed, and consideration is given to the occurrence of gases in molten metal and to the degassing of liquid metal either by "fluxing" with an insoluble gas as illustrated by the practice of bubbling chlorine through aluminium to remove hydrogen or by slow freezing with stirring. Reference is also made to the evolution of gas in castings depending upon: (1) The constitution of the gas-metal system; (2) the gas concentration; (3) the presence or absence of nucleating surfaces; and (4) the rate of freezing.

To a limited extent the "gases" present in solid metals are those absorbed at the time of melting and not evolved during freezing, but there are many opportunities for the further introduction of gases in the course of the many and diverse heating operations to which metals are subjected in the course of fabrication. The absorption or diffusion of hydrogen leads to hydrogen embrittlement in many alloys both ferrous and non-ferrous. Among examples cited are the zinc or cadmium plating of certain high-carbon steel springs intended for use in aircraft; the pickling of ferrous alloys; electroplating, particularly of iron, nickel and chromium if formed under conditions where a considerable quantity of hydrogen is released, resulting in brittleness and increased hardness; and the development of cracks in ferrous metals subjected to stress at elevated temperatures by the presence of dissolved hydrogen. Hydrogen also causes embrittlement in tantalum and palladium, and the electrical and magnetic properties of some metals are known to be slightly affected by the presence of dissolved hydrogen as when using Chromel-Alumel thermocouples in a moist hydrogen atmosphere at 1,000° C. The release of hydrogen from solid solution is also held responsible for a number of undesirable occurrences in the metal industries, such as the formation of pinholes in tinplate and blisters in wrought steel and aluminium products.

With few exceptions surface oxidation of pure metals proceeds either by diffusion of oxide through the oxide layer to meet and react with the metal or by the reverse process in which the metal diffuses outwards through the oxide layer to meet the oxygen. Alloys, on the other hand, oxidise in a variety of ways and thus give rise to a number of unanticipated effects. Wherever the minor component of any alloy forms the more stable oxide, sub-surface oxidation is possible, and the modes of occurrence of such oxidation are almost as numerous as the alloys in which they are observed and may be classified as one or a combination of types. In most cases oxidation proceeds by the inward diffusion of oxygen and the outward diffusion of the alloying element, the two meeting and reacting at an advanced interface below the outermost layer of metal.

The practical aspects of sub-surface oxidation generally arise either from the presence of weakening films of oxide or from the depletion of the surface zones of the metal in the alloying elements. Examples of such internal oxidation are the "birch-bark" effect in complex copper alloys used for springs, oxidation in certain steels containing residual aluminium or silicon which form a grain boundary sub-scale in the course of carburisation, the formation of rough surfaces on cold-drawn copper-chromium alloys that have been annealed in air, and the failure of Nichrome in the presence of hot air or carbon monoxide. Another group of effects of internal oxidation is to be associated with the withdrawal of an alloying element from solid solution, as in the case of age-hardening copper-beryllium alloys, which are particularly sensitive to internal oxidation due to the great reactivity of beryllium. A special case of internal oxidation is found in the handling of certain bi-metal products and is illustrated by the behaviour of silver-clad steel when heated for protracted intervals in air at temperatures as low as 425° C. Iron oxide forms near the junction of the two metals and the coating tends to spall, and oxygen which diffuses through the silver coating reacts with dissolved iron in a zone within the silver adjacent to the iron and also at the interface.

Rhines also discussed reduction of oxides contained in the solid solution of commercial metals and alloys. When such materials are heated in the presence of hydrogen, carbon monoxide or similar reacting gases, the hydrogen or carbon may diffuse into the metal and there reduce the oxides or react with the oxygen to form insoluble water vapour or one of the gaseous oxides of carbon. If this occurs where the products of reaction are confined, a considerable pressure may be generated and blisters or cracks formed as has been found in tough-pitch copper or galvanised iron. Related to the effect of reducing gases upon metals containing oxides is the effect of subjecting metals alternately to oxidising and reducing conditions. In the initial exposure, the metal becomes charged with oxygen or a reducing agent, but on subsequent exposure to the reverse condition a compound gas such as water vapour or carbon monoxide is formed within the metal and again gives rise to cracks, blisters and similar discontinuities. The precious and semi-precious metals are notably sensitive to alternate oxidation and reduction.

The solubility of stable nitrogen in the common solid metals is generally small, with the result that few technical important effects of dissolved nitrogen are recognised. Dissociated nitrogen, however, diffuses rapidly in iron at slightly elevated temperatures, produces unstable compounds with iron and greatly increases its hardness. Sulphur is similar to oxygen in its interaction with metals, and with nickel diffusion of sulphur takes place at the grain boundaries where a liquid film appears as the penetration progresses. This causes the nickel to become hot-short.

The most important deliberate application of gas-metal diffusion in industry is in the production of coatings by cementation. Among the cementation processes commonly employed are: Carburising, effected with carbon monoxide or other carbonaceous gases; calorising with aluminium, ferro-aluminium, or aluminium chloride; chromising with chromium, ferro-chrome or chromium chloride; irrigising with silicon,

ferro-silicon and silicon carbide with or without chlorides, boronising with boron powder or ferro-boron, sheardising with zinc or zinc salts, and stannising with stannous chloride.

### Diffusion in Alclad Steel

The results of tests by metallographic and solution potential methods of testing carried out by F. Keller, and R. H. Brown showed that very little copper will reach the surface of Alclad 24 S–T sheet by diffusion, when a temperature of 425° C. or lower is used. Any treatment, therefore, used for annealing or ageing will not cause a significant amount of diffusion. In Alclad 24 S–T material heat-treated in the normal temperature range 490° to 500° C., considerable copper will diffuse to the surface in an unduly long heat-treatment for any given thickness of material. Amounts of copper at the surface of the order of those shown will not affect the resistance to corrosion of the materials, if a sufficient rapid rate of quenching is used (Table II). When material is quenched under less rapid conditions, the amount of diffusion to the surface was found to be important when it changed the potentials to the point where adequate electrochemical protection was no longer obtained. It is assumed, therefore, that when Alclad 24 S–T is not quenched rapidly, the heat-treating conditions will be controlled to keep the amount of diffusion as low as possible, and adequate protective measures will be taken against the possibility of corrosive action.

TABLE II.

EFFECT OF QUENCHING RATE ON THE RESISTANCE TO CORROSION OF THIN GAUGE (0·020 IN.) ALCLAD 24 S–T SHEET (KELLER AND BROWN).

| Heat Treatment. | | Mechanical Properties. | | | Solution Potential. | | Potential Difference. | Copper at Surface, %. | Resistance to Corrosion. | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | Change in Properties, %. | |
| Time, Mins. | Quench. | Tensile Strength, T.s.i. | Yield Strength, T.s.i. | Elongation, % | Of Coating. | Of Core. | | | Tensile Strength. | Elongation. |
| 12 | Cold water | 28·4 | 17·5 | 20·0 | 0·814 | 0·680 | 0·134 | 0·27 | — 5 | —33 |
| 60 | „ | 28·9 | 18·1 | 20·5 | 0·782 | 0·677 | 0·105 | 0·85 | — 7 | —18 |
| 12 | Boiling water | 28·5 | 17·6 | 20·3 | 0·800 | 0·687 | 0·113 | 0·52 | — 4 | —26 |
| 60 | „ | 28·6 | 17·8 | 20·8 | 0·775 | 0·686 | 0·089 | 1·00 | — 6 | —21 |
| 12 | Air blast | 28·0 | 16·5 | 19·5 | 0·817 | 0·690 | 0·127 | 0·22 | — 2 | — 6 |
| 60 | „ | 28·9 | 18·0 | 20·5 | 0·784 | 0·695 | 0·089 | 0·80 | —25 | —77 |
| 12 | Air cool | 27·0 | 16·1 | 19·3 | 0·814 | 0·716 | 0·098 | 0·27 | —30 | —82 |
| 60 | „ | 27·4 | 16·4 | 19·5 | 0·783 | 0·712 | 0·071 | 0·82 | —62 | —90 |

### Diffusion of Indium in Bearings

Two different series of experiments were carried out by A. A. Smith to study the diffusion of indium into several metals, including refined lead (99·99%), cadmium containing 1·3% nickel, oxygen-free copper, sterling silver, and a lead alloy containing 12·5% antimony, 3·0% arsenic, and 0·75% tin. In the first series of experiments about 0·002 in. of indium was deposited, and diffusion was carried out at 150° C. for a period of 500 hours in a thermostatically controlled electric furnace, and in the second series of tests a layer of indium 0·0001 in. thick, an amount commonly used commercially on bearings, was deposited and diffusion was carried out at 120° C. for a period of 200 hours. The second series of tests was carried out as there was some surface oxidation of the indium plate in the first series due to the long heat-treatment which might have had some effect on the diffusion. The cadmium alloy also showed some incipient melting, which probably was caused by the formation of a low-melting point eutectic. The various alloys and the exact thicknesses of indium plate are given in Table III.

TABLE III.

THICKNESS OF INDIUM PLATE (SMITH).

| No. | Alloy. | Thickness of Plate, In. | Series No. |
|---|---|---|---|
| 1 | Refined lead (99·99) | 0·00197 | 1 |
| 2 | Cadmium + 1·3% Ni | 0·00220 | 1 |
| 3 | Oxygen-free copper | 0·00242 | 1 |
| 4 | Sterling silver | 0 00212 | 1 |
| 5 | Refined lead (99·99) | 0·00011 | 2 |
| 6 | Cadmium + 1·3% Ni | 0·000097 | 2 |
| 7 | 12·5% Sb, 3·0 As, 0·75% Sn, Pb remain | 0·0010 | 2 |
| 8 | Oxygen-free copper | 0·00008 | 2 |

In both series of experiments the depth of diffusion of indium was greatest in the cadmium alloy, followed by the lead alloys. With copper and sterling silver the depth of penetration of indium was relatively slight, the concentration approaching zero and only a few thousandths of an inch from the interface. In all cases concentration of indium at the surface remained relatively high, even after the more drastic diffusion experiments. As it has been shown that even as low as 0·37% of indium alloyed with cadmium bearing metals will markedly decrease the rate of corrosion in acidified lubricating oils, the data obtained show that extremely long times would be necessary before diffusion would progress to such an extent that the indium content at the surface would be below this amount, assuming that the weight of indium is less than 0·4% of the weight of the base metal.

### Diffusion in Chromising

The final paper of the symposium was given by I. R. Kramer, who called attention to the diffusion characteristics of chromium deposited on the surface of steel by treatment with chromium chloride and alloyed with the surface layer of the steel by thermal treatment. In a recently developed method of chromising, gaseous chromium chloride and hydrogen are passed over the steel at a temperature of 900° to 980° C. The chromium chloride reacts with the iron to give chromium and iron chloride. The chromium atoms being deposited on the surface diffuse inwards as the iron atoms diffuse outwards forming a layer rich in chromium. The principal role of hydrogen is to remove the carbon from the surface of the steel. As the diffusion is slower than the chemical reaction, its rate affects the process, and the rate of diffusion is influenced by the temperature. Depth-concentration studies show that the concentration falls off gradually for a considerable distance at about 13% chromium.

The influence of composition of the base metal upon diffusion is quite important. The depth of penetration of the chromium decreases as the carbon content increases, and, of more importance, the chromised layer becomes brittle and is likely to spall if the carbon content is too high. In order to chromise successfully, the carbon must be fixed by strong carbide-forming

elements, such as chromium or molybdenum, which decrease the diffusion of carbon. If this is done, the carbon diffuses from the interior faster than the chromium can diffuse inwards, thus forming a carbide barrier.

The corrosion resistance of the chromised layer is high, and chromised steels offer some unique advantages over other corrosion-resisting castings or alloys. While chromising is not meant to replace stainless steels, it may serve in the saving of alloying elements. The chromising process uses soft or low alloy steels, which can be formed easily either hot or cold, and since the chromised layer is soft and firmly adherent, chromised parts can be subjected to cold deformation without spalling, chipping and without loss of corrosion resistance.

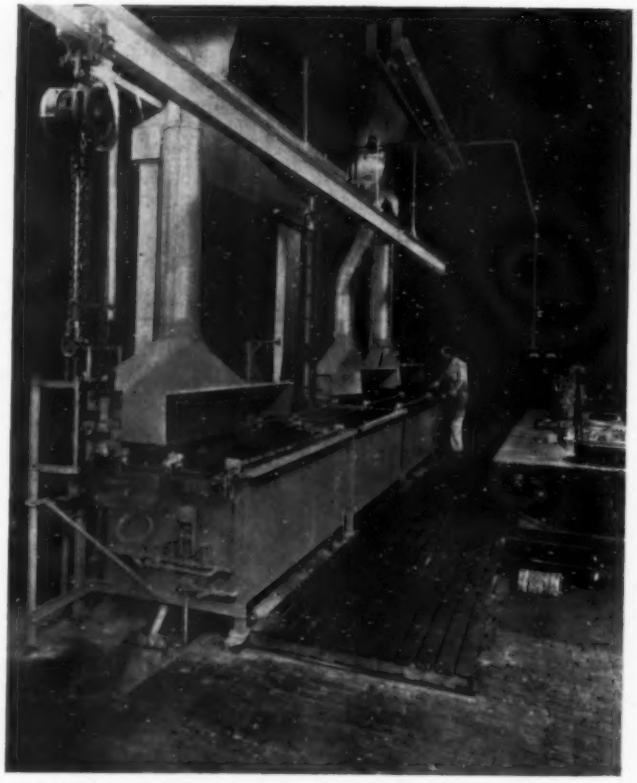
# An Electro-Chemical Descaling Process

IN many heat-treatment processes some form of surface treatment is subsequently required, and a unique plant designed for this purpose is shown in the accompanying illustration. It embraces the Bullard-Dunn Process (handled in this country by the Electro Chemical Engineering Co., Ltd.), which is an electro-chemical method of removing scale and oxides from the surface of metals, particularly the ferrous metals. Its characteristic feature is that a continuous and non-porous metal film, usually tin, electrodeposited on the work simultaneously with the scale and oxide removal, completely protects the work surface from pitting and etching. This metal film can be removed easily and completely, although it is usually advantageous to permit it to remain on the work.

The surface of the work is not damaged, regardless of the length of treatment time, therefore this process is being used on classes of work where requirements demand no dimensional change; for example, rubber moulds, precision threaded parts, dies and gears.

This process is practical both from the cost and operating standpoints. It is easy to keep in continuous operation since it requires no rigid chemical, electrical, or temperature controls. Technically trained operators are not required. The chemicals employed are simple, inexpensive, non-poisonous, and in abundant supply. The unique advantage of the process is the high "throwing power" it possesses which enables it to remove scale from recesses and internal surfaces. It is therefore being used with success to clean such parts as Diesel engine nozzles, hydraulic control valves, aeroplane engine oil pipes, air compressor parts, gears and dies. In addition, the process has been found especially useful prior to the application of general classes of electroplating, electroplating for heat-treatment stop-off, hot dipping and other coatings. The scale is claimed to be so thoroughly removed from heat-treated work that subsequent grinding operations are done at minimum cost. Assembly of parts is also facilitated. More accurate inspection can be made since the complete removal of the oxidation brings to light minute heat cracks and checks which might otherwise be overlooked.

The life of the acid-descaling solution is long, because none of the base metal is dissolved, and the process operates efficiently at high iron concentrations. Dumping of this solution can be eliminated by the use of crystallising equipment to remove the excess iron where circumstances make this procedure practical. In such cases, uniform and uninterrupted operation is possible.



**A batch-type Bullard-Dunn installation for gear-wheels.**

The process utilises electric current which greatly shortens the time required for the removal of scale. Current can be used with impunity since the protective metal film, electro deposited on the base metal, prevents the pitting and etching which would otherwise take place. Direct current at 6 volts or less and a current density of 60 amperes per sq. ft. is sufficient. Time required for descaling is independent of the size of a piece and practically independent of its shape.

# Examination of Various Fuel and Header Tanks taken from Captured Enemy Aircraft

By The Staff of Metallurgy Division, Royal Aircraft Establishment

*This report constitutes a summary of data resulting from the metallurgical examination of parts from enemy aircraft carried out at the request of the Committee on Non-Ferrous Metal Parts of Enemy Aircraft. The parts examined represent various fuel and header tanks taken from a Messerschmitt* 109, *a Heinkel III, a Fiat Cr.* 42, *and a Focke Wulf* 190.

THE following report deals with components from the Messerschmitt 109 (header tank and fuel tank), Heinkel III (fuel tank), Fiat Cr. 42 (fuel tank) and Focke Wulf 190 (drop tank). Taking these in the order named, a general view of the header tank of the Messerschmitt 109 is given in Fig. 1, while Fig. 2 shows one-half of this tank with a side cut away and also a cross-section through the swill chamber of the other half tank.

The tank shell is constructed from aluminium alloy panels, welded together. The dished panel indicated by arrow "A" in Fig. 1 is 12G, and the front panel " B " is 14G.

The remaining panels are 16G thick. The swill chamber, an extension of which forms the inlet pipe, is a light alloy casting, welded to the shell and to the outlet pipe. The outlet pipe is formed from welded light alloy sheet, and is also welded into the shell at its exit from the tank. The attachment of the balance valve, relief valve and vent pipes is also made by welding. Fig. 3 shows one of these welds and the method of attachment of the pipes.

The light alloy material has not been given any protective treatment other than a coating of paint on the outer surface. A slight amount of corrosion of the inner surface of the sheet in a few isolated areas can be observed.

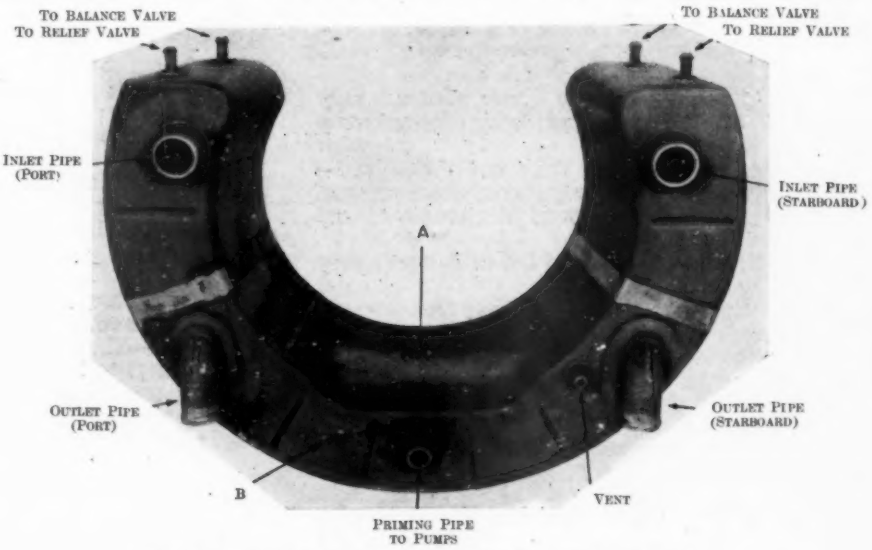



**Fig. 1.—General view of header tank of Messerschmitt 109.**

TABLE I.
CHEMICAL ANALYSES OF MATERIALS USED.

| | Sheet Material. % | Swill Chamber Casting. % |
|---|---|---|
| Silicon | 0·86 | 5·36 |
| Magnesium | 0·79 | 0·56 |
| Manganese | 0·49 | 0·50 |
| Iron | 0·22 | 0·33 |
| Copper | nil | 0·07 |
| Titanium | 0·02 | 0·02 |
| Nickel | nil | trace |
| Aluminium | remainder | remainder |

## Chemical Analyses

Chemical analyses have been made on the sheet material and on a portion of the swill chamber casting. The results are given in Table I.

The sheet material is " Anticorodal." Soft aluminium alloy sheet of this composition is covered by specification D.T.D. 346. The 5% silicon-aluminium alloy of which the swill chamber casting is made has no British equivalent, the American alloy known as No. 43 is similar.

## Mechanical Tests

*Hardness Tests.*—Sections of the parts and various welds have been subjected to diamond pyramid hardness tests (HD/5) which gave the following results :—

(*a*) *Sheet Material.*—Hardness figures of the order of 90 to 110 are recorded on the material away from the welds. The hardness of the sheets falls rapidly towards the welds to a minimum of 45. This softening of the alloy of the sheets occurs in the regions of all the welds.

(*b*) *Swill Chamber Casting.*—The hardness values obtained vary from 45 to 50. There appears to be a very slight increase in hardness near the welds.

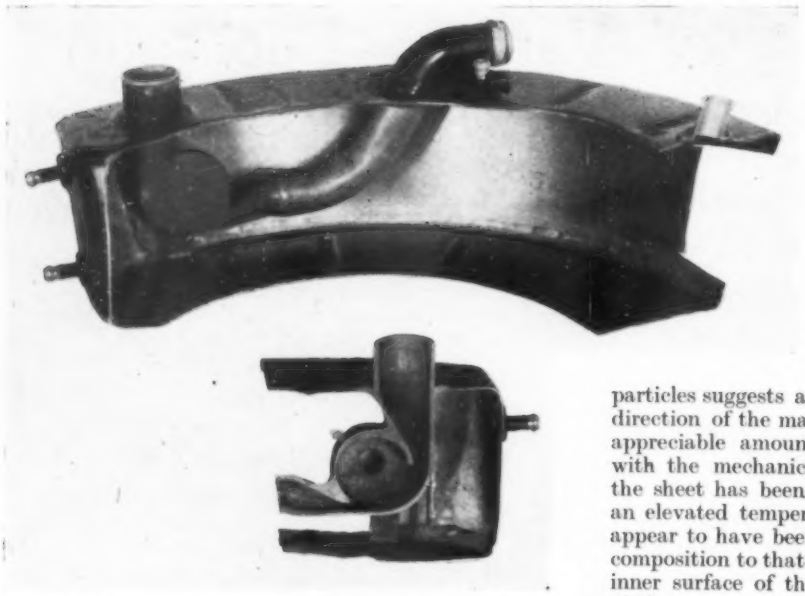


**Fig. 2.—Part of header tank with side cut away and also section through swill chamber.**

(*c*) *Outlet Pipe.*—Hardness figures obtained vary from 45 to 50, the higher figures being obtained away from the welds.

(*d*) *Balance Valve, Relief Valve, and Vent Pipes.*—All the pipes are of similar hardness of the order of 75 to 80 away from the welds and falling to a minimum of 45 near the welds.

(*e*) *Welds.*—The hardness of the welds varies very little, being between 45 and 50.

*Tensile Tests.*—Tensile test-pieces have been prepared from the sheet material of the shell. Test-pieces Nos. 1 and 3, from the top and the bottom portions of the tank respectively contain transverse welds. Nos. 2 and 2a, which do not include welds, are respectively from the centre of a panel and from a region adjacent and parallel to a weld. The results obtained are as given in Table II.

TABLE II.

TENSILE TESTS ON SHEET MATERIALS.

| Position of Specimen. | Through Weld at Top of Tank. | Centre of Panel. | Adjacent to Weld. | Through Weld at Bottom of Tank. |
|---|---|---|---|---|
| Test No. | 1 | 2 | 2a | 3 |
| Cross-section dimensions, in. | 0·751 × 0·058 | 0·502 × 0·058 | 0·501 × 0·059 | 0·748 × 0·058 |
| Gauge length, in. | — | — | 2 | — |
| L.P., T/in.² | — | — | 4·5 | — |
| 0·1% proof stress, T/in.² | — | — | 8·6 | — |
| 0·2% " " | — | — | 9·2 | — |
| 0·5% " " | — | — | 9·9 | — |
| Max. stress, T/in.² | 11·7 | 19·4 | 12·9 | 11·3 |
| Young's Mod. (E) × $10^{-6}$ lb./in.² | — | — | 9·5 | — |
| Elongation on 2 in., % | — | 8·0 | 8·5 | — |
| Position of failure | ¾ in. from weld | — | — | ¾ in. from weld |

The maximum stress value of 19·4 tons per sq. in., with a hardness of 90–110 is usual for solution heat-treated and aged Anticorodal sheet. The reduction of the maximum stress value to 12·9 tons per sq. in. and of the hardness to 45 in areas adjacent to the weld are the result of softening of the alloy during welding.

## Microscopical Examination

Sections were prepared from various parts of the tank and examined microscopically. The results of the examination are classified under the following headings :—

1. *Sheet Material.*—All the panels of the tank examined appear to be of alloy of similar composition to the one chemically analysed, although the 12G sheet seems to have a slightly higher silicon content.

The banding of the hard particles suggests a greater amount of rolling in the direction of the maximum strength. The absence of appreciable amounts of magnesium silicide together with the mechanical properties would suggest that the sheet has been solution heat-treated and aged at an elevated temperature. The welds are sound and appear to have been made with a filler rod of similar composition to that of the sheet. The corrosion of the inner surface of the tank has resulted in very slight pitting.

2. *Swill Chamber Casting.*—The structure is typical of a sand casting of a 5% silicon-aluminium alloy in the modified state and not subsequently heat-treated. Unsoundness is present as gas blow-holes and also as shrinkage cavities throughout the material. These holes are up to 0·02 in. in diameter. The welds at the junctions of the swill chamber with the shell and the outlet pipe appear to have been made with filler rod of the Anticorodal type, and are fairly sound, though not as sound as those encountered in the sheets.

No corrosion of the swill chamber or of the welds can be observed.

3. *Pipes.*—The outlet pipe which is formed from sheet appears to be made in alloy of the Anticorodal type. The welds in the pipe are sound, though one of the seam welds at one point is defective and contains non-metallic inclusions. At this point the weld

**Fig. 3.—Showing the method of attaching pipes. × 2.**

is discontinuous and leakage of the coolant into the tank or vice versa must have occurred in service.

The balance valve, relief valve, and vent pipes have similar structure to that of Anticorodal. The macrostructure as shown in Fig. 3 shows that these pipes have been machined from bar. The welds are sound, but the penetration is considered to be poor.

### Accelerated Corrosion Tests

Specimens from the sheet material, including the welds, were exposed to accelerated corrosion test for 24 hours. The test consists in partly immersing the specimen in a solution of sodium chloride acidified with hydrochloric acid. Microscopical examination of sections of the specimen after immersion reveal corrosion at the surfaces of all the sheets to a marked degree. The corrosion is both of the intergranular and pitting types. The greatest amount of corrosion has taken place on the inner surface of the welds and in the sheet adjacent to the welds. The sheet away from the welds has also suffered intergranular corrosion, particularly in the direction of final rolling—i.e., in the direction of the bands of hard particles.

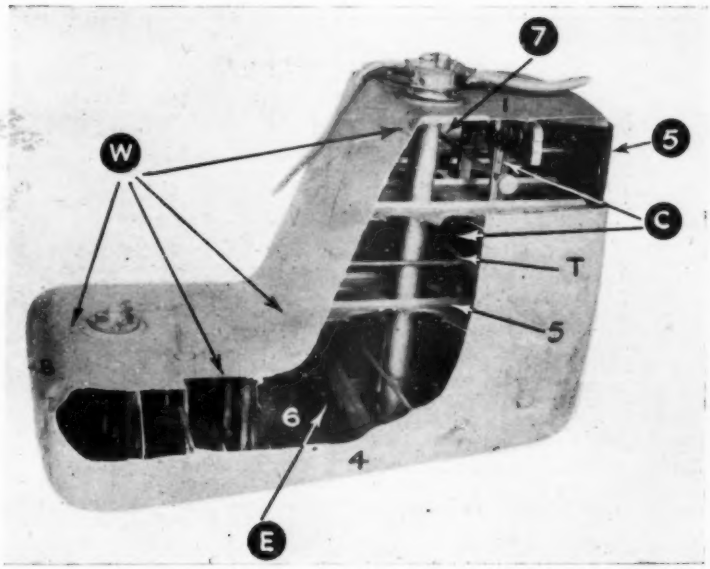



**Fig. 4.—Fuel tank of Me. 109 with part cut away to show interior construction.**

### Discussion of the Welding

Visual examination of the welds, together with the apparently extended heating of the sheets, as shown by mechanical tests at either side of the welds, would suggest that gas-welding has been used throughout. The welding rod has been of the Anticorodal type. The shell has been welded from the outside and the penetration is considered to be good. The thickness of the welds is much greater than is usual in British practice and is probably the result of " heavy " welding with a thick welding rod. Apart from a little hammering of the inner surfaces of some of the sheet welds, the welds have not been dressed.

### Comments and Conclusions

The tank shell has been constructed from aluminium alloy sheet, panels of the material having been butt-welded together. The material is the alloy known as Anticorodal, which, in the form of softened sheets, is covered by specification D.T.D. 346. The sheet material has been solution heat-treated and aged. The outlet pipe and the smaller pipes are also made in alloy of the Anticorodal type.

The swill chamber and the inlet pipes are in the form of a single sand casting in 5% silicon-aluminium alloy. The casting is very unsound.

Gas-welding, using a welding rod of alloy of the Anticorodal type, has been used throughout. The penetration and the soundness of the welds are fairly good, but the welds are much heavier than those normally allowed in good British aircraft practice. The method employed to join the smaller pipes to the tank shell, as shown in Fig. 3, is simple and efficient. The joint would have been further improved, however, by a higher standard of welding.

Mechanical tests reveal extensive softening of the alloy during welding. The welding of light alloy sheet in the heat-treated and aged condition is not practised in this country.

The materials of construction of the tank have not a high resistance to corrosion, the welds being particularly susceptible to intergranular breakdown under the accelerated corrosion test. In service, however, only slight pitting of the sheets in a few isolated areas has occurred.

The quality of the castings and the standard of welding are considered to be rather below those generally obtaining in British aircraft practice, although the behaviour of the tank in service has evidently been satisfactory. Higher tensile properties and greater resistance to corrosion would have been obtained if the complete tank had been heat-treated. Even without heat-treatment, however, a stronger tank has resulted from the use of heat-treated sheet than would have resulted from the use of half-hard or soft aluminium.

### The Fuel Tank (Me. 109)

Fig. 4 shows that the fuel tank of this machine is roughly in the form of the letter " L." It has no self-sealing covering, and is fitted in the fuselage directly behind the pilot's seat, but separated from the cockpit by a bulkhead—the foot of the " L " passing under the seat. The capacity of the tank is 409 litres—i.e., 90 gals. (dip-stick reading) and the weight 58 lb.*

The tank is slung on two webbing straps which pass around the rear face under the bottom. A further supporting strap made of light alloy, passes under the bottom 18 in. from the rear face and perpendicular to the webbing. This is prevented from rubbing against the tank by a padding of thin sheet rubber.

* Two 0·303 in. bullet entry holes were found near the bottom of the rear face of the tank. Both these bullets appear to have been turned broadside on by the fuselage structure. Neither of the bullets have made exit holes. These holes would have emptied the tank in a very short time.

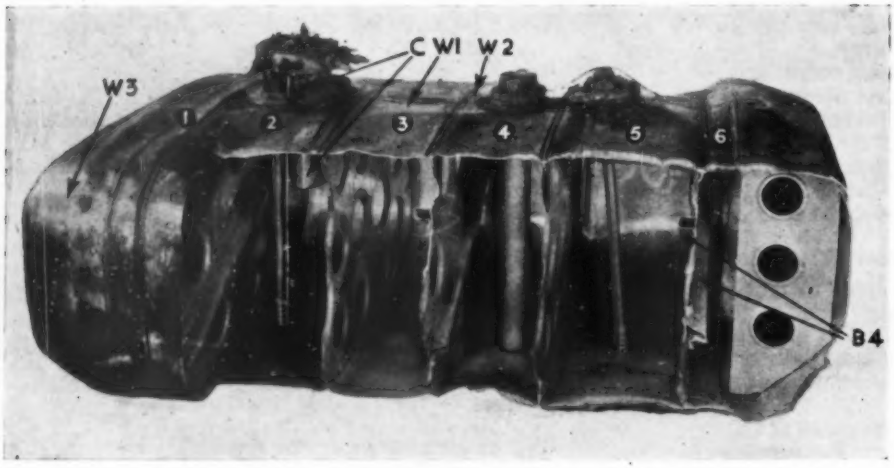



**Fig. 5.—General view of fuel tank of Heinkel III, with most of one side removed to show arrangement of baffles, etc.**

To remove the tank from the fuselage, a panel, forming a section of the fuselage under the tank, has first to be removed. By undoing about 48 screws in the supporting straps the tank can be lowered from position.

## Materials and General Construction

The appearance of the tank, partly sectioned, is shown in Fig. 4. The structure has been painted, but not anodised. The chemical compositions of the various materials used have been determined and are given in Table III.

TABLE III.

CHEMICAL COMPOSITIONS OF MATERIALS
(Fuel tank Me. 109).

| Item. | Composition. | | | | | | Material. |
|---|---|---|---|---|---|---|---|
| | Si. | Mn. | Cu. | Fe. | Mg. | Ti. | |
| Shell | 0·25 | nil | nil | 0·31 | 0·10 | — | Aluminium |
| Baffle plate | 0·30 | nil | nil | 0·34 | 0·10 | — | Aluminium |
| Stiffening angle | 0·33 | nil | nil | 0·31 | 0·03 | — | Aluminium |
| Tubular stiffener | 0·97 | 0·79 | tr. | 0·53 | 0·86 | tr. | Anticorodal |
| Channel stiffener | 0·41 | 0·44 | 4·27 | 0·41 | 0·88 | tr. | Duralumin |
| End fitting for stiffener | 0·99 | 0·81 | tr. | 0·39 | 0·85 | 0·04 | Anticorodal |
| Ring for attachment of fuel pipe (welded to tank) | 1·06 | 0·81 | tr. | 0·36 | 0·88 | tr. | Anticorodal |

N.B.—Specification D.T.D. 423A covers extruded bar, which may be similar to Anticorodal.

The shell of the tank is formed from eight panels of aluminium sheet 0·058 in. thick, joined together by welding. The panels are numbered in Fig. 4, and some of the welds are indicated by arrows W. The top of the tank and the aluminium baffle plates, some of which are 18G and others 20G thick, have been stiffened by being spot-welded to aluminium angle, as shown at S in Fig. 4. The edges of the baffle plates have been bent through a right-angle and the bent-over edge spot-welded to the shell as shown at E in Fig. 4. The junction has been strengthened by the insertion of aluminium-angle, which is riveted to the baffle plate and spot-welded to the shell.

The tubular stiffeners visible in Fig. 4 are 12 mm. o/d and 1 mm. wall thickness. A corrosion-resisting film is present on the tubes. The film is grey in colour and is thought to have been produced by the MBV. immersion process.

No protective film can be found on the baffle plates or on the tank shell. Two types of anodised end fittings have been employed for the tubular stiffeners. In both types the tubes are riveted into the end fittings, and a washer of synthetic rubber or other petrol-resisting material is present between the outer surface of the shell and the outside portion of the end fitting. The end fitting is provided with circular ridges that press into the rubber washer when the fitting is screwed home. The hexagon heads of the end fittings are connected by zinc-plated steel wire to prevent the ends from unscrewing. The wire is covered with doped fabric. The shell of the tank has been dished locally to accommodate the outside portions of the end fittings. In the places where the tubular stiffeners cross they are tied together by means of zinc-coated steel wire, the ends of the wire being soldered together to prevent untwisting, as shown at T in Fig. 4.

In addition to the tubular stiffeners, there are two vertical stiffeners of channel section at the deep end of the tank. These are indicated by C in Fig. 4. They are attached by nuts and bolts to a vertical baffle plate at the top of the tank and to end fittings on the bottom of the tank. The nuts and bolts employed on the end fittings are of cadmium-coated steel. Spring washers have been used under the nuts and no other locking device has been adopted.

The ring seatings provided for the sttachment of the petrol gauge, pipe-unions, etc., have been formed by hot stamping and are attached to the shell by welding. The all-metal unions are of a type previously encountered in German aircraft.

The sequence of operations in the building of the tank cannot be stated with certainty. It is apparent, however, that the top panel No. 1 and the small front panel No. 8 are the last to be welded into position. The angles on the surfaces of the baffle plates are doubtless spot-welded before the plates are inserted. It is also probable that the angles attached to the edges of the baffle plates are spot-welded to the shell panels before assembly. The spot-welding of the turned-over edge of the baffle plate to the shell, and the riveting of the edge angle to the baffle plate would have to be done from the top or front of the tank.

## Examination of Welds

The general superficial appearance of the weld seams joining the tank shell panels suggests that they have been made by the electric arc welding method rather than by oxy-acetylene. The joints have a considerably smoother finish than electric arc welds in aluminium of

similar gauge made by a firm in this country and examined here.

Microscopical examination of a section taken from across the welds shows the structure to be substantially sound ; the fused metal at the weld appears to be of a similar composition to that of the sheets. If the carbon arc method has been employed, as is probable, the welding would not necessarily entail the use of a welding rod.

The spot-welds are only of moderate quality. In some instances they are ineffective, but the number of welds ensures a reasonable factor of safety.

### Mechanical Tests

Tables IV and V give the results of tensile and hardness tests made on portions cut from the tank shell (including unwelded and welded portions) and from the tubular stiffeners.

TABLE IV.
TENSILE TESTS.

| — | Tank Shell. | | Tubular Stiffener. |
|---|---|---|---|
| | Unwelded. | Welded. | |
| Sectional dimensions, in. | 0·058 × 0·490 | 0·058 × 0·503 | 0·041 wall × 0·472 o/d |
| Gauge length ..... | 2 | 2 | 2 |
| Max. stress ..... | 6·3 | 4·9 | 17·9 |
| Elongation, % ..... | — | Failed clear of weld | 23·5 |

TABLE V.
HARDNESS TESTS.

| Material. | Hardness. | Tensile Strength, T/in.² |
|---|---|---|
| (a) Shell ..... | 31·9, 32·5, 38·7 | 6·3 actual value |
| (b) Tubular stiffener ..... | 85·4, 89·2, | 17·9 " " |
| (c) Channel stiffener ..... | 133, 131 | 27–30 estimated value |
| (d) Angle stiffener, spot-welded to baffle ..... | 34, 35, 36 | 6–7 " " |
| (e) Angle stiffener, riveted to edge of baffle ..... | 31, 32 | 6–7 " " |
| (f) Ring for attachment of petrol gauge | 50, 50, 50 | 9–10 " " |

### Conclusions

The main findings can be briefly summarised as follows :—

(1) The shell is of 17 gauge, 0·058 in. thick, soft aluminium of 6·3 tons per sq. in. tensile strength. It is made up of panels welded together probably by the carbon arc process. These welded seams are of very good appearance. The strength, however, has been reduced locally to a value of 4·9 tons per sq. in. by the welding.

(2) The baffle plates and stiffeners are of soft aluminium.

(3) The baffle plates are attached to the tank wall by spot-welding. Similarly, the stiffening angles on the surface of the baffles and on the top of the tank have been secured by spot-welding.

(4) Riveting is only used for attaching some angles to the outer edges of the baffles which are in turn spot-welded to the tank wall.

(5) The tubular stiffeners and end fittings are in Anticorodal alloy corresponding approximately to specification D.T.D. 423A. The Duralumin channel section stiffeners have a tensile strength of about 27–30 tons per sq. in.

(6) There has been little attempt at corrosion protection. The outside surface is painted and some small parts have been anodised. The stiffeners appear to have been treated by the MBV. immersion process.

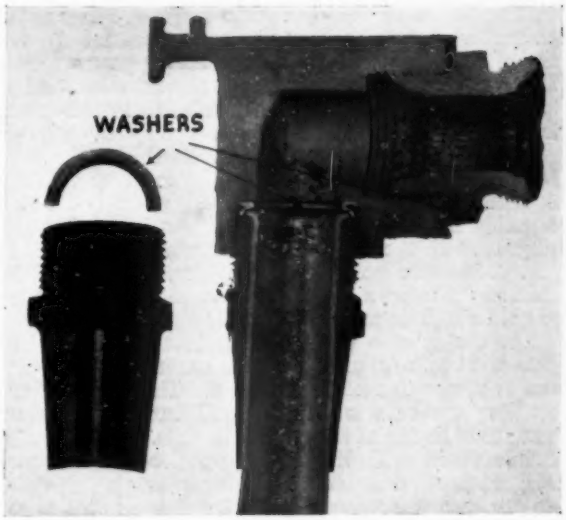



**Fig. 6.—Showing union between an internal pipe and a head unit casting. × ⅔.**

### Fuel Tank (Heinkel III)

This metal tank is of particular interest, as all previous Heinkel fuel tanks examined by the Royal Aircraft Establishment have been made of vulcanised fibre. It is rectangular in shape, roughly 60 in. × 42 in. × 20 in., giving a capacity of approximately 700 litres—i.e., 165 gals. (taken from the dip-stick markings). It is therefore probable that these metal tanks are interchangeable with the fibre tanks previously examined.

The tank is provided with a self-sealing covering, similar in construction to that examined on a Focke Wulf Condor oil tank. This covering had been severely damaged by fire, thus making detailed examination difficult. The weight of the metal tank stripped of the self-sealing covering is 82 lb., and though the weight of the covered tank could not be obtained, due to the fire, it is probable that this weight will be approximately 260 lb., compared with 240 lb. for the corresponding fibre tank.

### Construction

The general appearance after removal of most of one side, to show the internal arrangement of baffles, etc., is reproduced in Fig. 5. As is shown in the photograph, the tank has been constructed by welding together eight transverse segments—i.e., the two ends and six intermediate sections. Each of the six sections in the body of the tank has been made by welding together the ends of a length of sheet or strip 0·060 in. thick. The appearance of the joint indicated by arrow W1 in Fig. 5 suggests it has been made by the oxy-acetylene method, and that it has been made prior to the transverse welds, one of which is shown by arrow W2, joining the adjacent sections together. These transverse welds which have the " heavy " appearance usually associated with arc welds are slightly recessed by preliminary forming of the edges of the sheet ; a narrow strip has been introduced on the inner side and welded simultaneously to give a T-type joint and to provide a flange to which the 0·040 in. thick baffles are riveted.

The two end sections of the tank have been made from single sheets, 0·065 in. thick, suitably cut and

welded at the corners as at W3 (Fig. 5). Two small baffles inserted in each end have been attached by a few rivets interposed by spot-welds of poor quality. Three out of the five transverse baffles have been cross-braced with channel section members, riveted on as indicated by arrows B4 in Fig. 5.

The three heavy stampings on the top of the tank have been joined to the wall of the tank by welding. A small auxiliary container of 2½ pints (1,400 c.c.) capacity made from aluminium sheet, gas-welded, is suspended in the tank. This container, marked C in Fig. 6, has two communicating pipes, one of which is marked " Einspritz P " and is assumed to be intended to hold a high octane starting fuel.

The design of a typical union between an internal pipe (0·71 in. o/d) and head unit casting is of interest, and is shown in section in Fig. 6. The design of the coupling necessitates only a small but locally severe amount of flaring at the end of the pipe. The retaining ferrule which holds the pipe in position has a tapered wall thickness designed, no doubt, to support the pipe and to reduce localised fluctuating stresses that might lead to fatigue failure. Fabric-cored soft metal washers are used, as shown in Fig. 6.

The results shown in Table VI were obtained of chemical analyses of the main component parts, which are all made in aluminium rich alloy :—

TABLE VI.

CHEMICAL ANALYSES OF MAIN COMPONENT PARTS.

| Component. | Analysis. | | | | | Material Type. |
|---|---|---|---|---|---|---|
| | Si. | Cu. | Mn. | Mg. | Fe. | |
| (1) Tank wall, 0·060 in. thick ..... | 0·35 | nil | nil | tr. | 0·22 | Commercial aluminium |
| (2) Baffle, 0·040 in. thick ..... | 0·51 | 0·07 | 0·02 | tr. | 0·45 | " " |
| (3) Channel, 0·048 in. thick ..... | 1·04 | nil | 0·77 | 0·66 | 0·42 | Anticorodal (DTD.346) |
| (4) Internal tube, 0·71 in. o/d × 0·048 in. ..... | 0·30 | 0·05 | 0·16 | 6·82 | 0·36 | Hydronalium Mg7 |
| (5) Head unit casting | 0·57 | nil | 1·24 | 1 45 | 0·45 | — |
| (6) Rivets ..... | 0·29 | 0·20 | 0·30 | — | — | Similar to DTD.327 |

The composition of the casting is unusual. Only a few isolated parts of the assembly have been anodised or otherwise protected against corrosion. There is, however, no indication of corrosion on the unanodised parts.

## Self-sealing Covering

The self-sealing covering consists of three layers, of which the innermost is black vulcanised rubber, the next being yellow unvulcanised rubber, and the outermost again black vulcanised rubber. These layers are all cemented together, but the innermost layer does not appear to be cemented to the tank wall. The innermost layer is 0·165 in. thick, weighs 16 oz. per sq. ft., and contains 3·8% nitrogen ; it is probably synthetic rubber of the Perbunan type.

The other layers were too badly damaged by fire to permit of detailed analyses, but the yellow intermediate layer is soluble in petrol and appears to be identical with the similar soft yellow rubber taken from other German protected tanks. The outer layer contains a considerable quantity of nitrogen, and is probably Perbunan, like the inside layer.

The covering weighs approximately 2·8 lb. per sq. ft., and is about 0·7 in. thick. It appears to be similar in construction to that used on the Focke Wulf Condor oil tank. Due to the damaged nature of the covering it is impossible to make firing tests on this tank, but previous experience has shown that this type of covering will probably provide a useful degree of protection against straight and broadside-on 0·303 in. bullets.

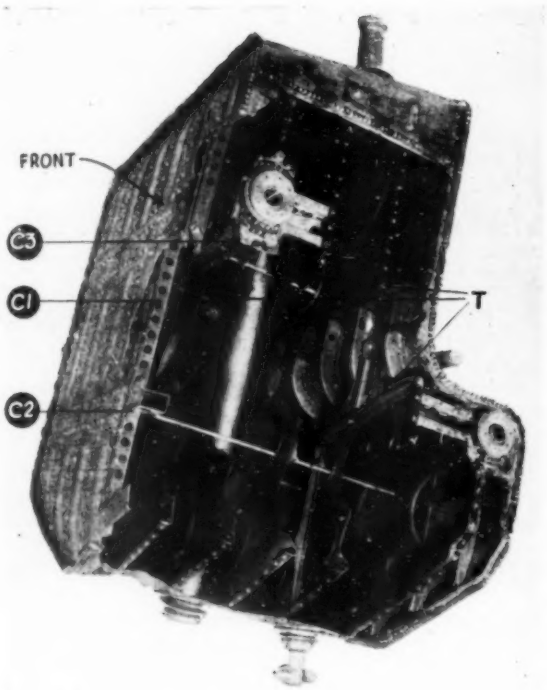



**Fig. 7.—General view of fuel tank of Fiat Cr. 42, with port side and half of bottom cut away.**

No evidence as to the method of mounting the tank in the aircraft is available.

## Fuel Tank (Fiat C.R. 42)

Two fuel tanks are carried on this machine—in the fuselage behind the engine fireproof bulkhead. The forward one is " L " shaped, the foot of the " L " facing the pilot. The rear fuel tank is fitted in line with the foot of the " L." The total capacity of these tanks is 350 litres—i.e., approximately 77 gals., this figure being shown on the pilot's fuel contents gauge. Each tank is provided with a self-sealing covering, similar to the Semape system used on some British aircraft.

The two tanks have a common filler cap situated in the forward one. They are joined by a pipe which automatically adjusts the petrol level in the two. A single " Televel " type contents gauge is fitted, from which the total fuel load can be read. This gauge works mechanically, by jamming a float in a vertical cylinder at the petrol level by means of a Bowden wire arrangement. Before a reading can be taken, the gauge must be placed in a " free " position to allow the float to take up the true level of petrol in the tank.

### Construction

Both tanks appear to be of the same construction, being made from high strength thin gauge Duralumin. The amount of riveting entailed in assembly is notable. The design and construction are not regarded as being novel.

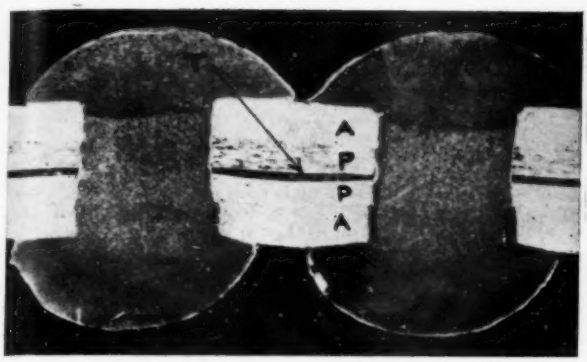



**Fig. 8.—Showing construction of a typical joint. × 4½.**
A—Duralumin Strip. P—Panel. T—Tin Sheet.

As regards the main tank, the appearance with the port side and half of the bottom cut away is shown in Fig. 7. The large amount of riveting used in assembly is a prominent feature, the closeness of pitch and the multiplicity of joints entailing the use of a very large number of rivets. Although special attention has been paid to the method of riveting in order to ensure petrol tightness, the addition of an external coating of a black organic material bound by surface strips of fabric suggests that absolute petrol tightness has not been attained by riveting.

None of the aluminium alloy materials have been given anodic or any other surface protective treatment against corrosion.

## Materials

The main items comprising the finished tank are :—

(*a*) Tank shell in 21 to 20 gauge (0·032 in. to 0·036 in. aluminium alloy sheet).
(*b*) Channel stiffeners. 21 and 18G aluminium alloy sheet.
(*c*) Baffles, 21G aluminium alloy sheet.
(*d*) Steel stiffeners, 0·275 in. diameter, interconnecting the front and rear walls of the tank.
(*e*) Rivets, light alloy.
(*f*) Sealing washer and beading materials—(i) tinfoil 30G. (ii) aluminium alloy 18G.
(*g*) White metal filling.
(*h*) Inorganic sealing material.

The front and back of the tank have suffered marked corrosion, apparently by the adhesive used for securing the self sealing covering. The remainder of the shell is not obviously corroded.

The chemical compositions of selected materials were determined, and the results obtained are given in Table VII.

TABLE VII.
ALUMINIUM ALLOYS.

| Item. | Composition. | | | | | Material Type. |
|---|---|---|---|---|---|---|
| | Si. | Cu. | Mn. | Mg. | Fe. | |
| (*a*) Tank shell | 0·81 | 4·07 | 0·73 | 0·76 | 0·31 | Duralumin |
| End panel | 0·26 | 3·90 | 0·57 | 0·88 | 0·31 | ,, |
| (*b*) Small channel (C1, Fig. 10) | 0·29 | 3·72 | 0·64 | 0·65 | 0·36 | ,, |
| Larger channel (C2, Fig. 10) | 0·33 | 3·95 | 0·58 | 0·65 | 0·31 | ,, |
| (*c*) Baffles | 0·46 | 3·71 | 0·65 | 0·69 | 0·39 | ,, |
| (*e*) Rivets | 0·21 | 3·96 / 3·74 | 0·52 | 0·54 | 0·25 | ,, |

**Fig. 9.—Method of securing steel rod stays to tank shell.**

*Steel Stiffeners.*—The chemical composition of the material of the steel stiffeners was not determined, but other examination showed the steel to be of a high tensile type which has been cadmium plated. It has a hardness of 285 (HD/10) which corresponds approximately to a tensile strength of about 50 tons per sq. in.

*Soft-washer Foil Material* (30G.).—Tin 99·5%

*White Metal Filling at Joint of Steel Stiffener with Tank Wall.*—Tin, 69·3% ; lead, 30·2%.

This white metal filling material can be regarded as a solder, although the tin content of solder rarely exceeds about 63%.

*Inorganic Material Applied to Outer Surface of Tank along Riveted Joints.*—This material, which is black in colour, has been found to be a celluloid resin, insoluble in petrol. It has become brittle with age and its adhesion to the superimposed treated fabric is poor.

## Mechanical Properties

Tensile and bend tests were made on a sample from the tank shell, and hardness tests were made on this and on other sheet materials.

The results obtained are as follows :—

(i) *Tensile test on tank shell material.*

| | |
|---|---|
| Cross-section dimensions, in. | 0·502 × 0·0326 |
| Maximum stress, tons/sq. in. | 28·8 |
| Elongation, % | 20·0 |

(ii) *Limiting Radius Bend Test on Tank Shell Material.*—$r = 2t$, uncracked ; $r = t$, cracked.

(iii) *Hardness Tests*, HD/10.

| Item. | Hardness. | | | | |
|---|---|---|---|---|---|
| Tank shell | 134 | .. | 135 | .. | 131 |
| End panel | 114 | .. | 112 | .. | 116 |
| Channel (C1, Fig. 10) | 131 | .. | 124 | .. | 131 |
| Channel (C2, Fig. 10) | 110 | .. | 110 | .. | 110 |
| Baffle | 114 | .. | 114 | .. | — |

The lower range of hardness values is normal for age-hardened Duralumin. The values in the higher range could be obtained by cold-working after ageing.

## Construction of Typical Joints

The main feature of the riveted joints is the use made of tinfoil (30G approximately) to ensure petrol tightness. In the attachment of baffles and channel section stiffeners to the wall of the tank, the rivets, $\frac{1}{8}$ in. shank, are driven through an aluminium alloy washer, $\frac{9}{16}$ in. outside diameter × 18G. and then through a second washer made from tin sheet or foil, 0·012 in. thick, before entering the tank wall proper. The preformed heads of the rivets are at the outer surface of the tank.

The edges of the front and rear panels have been flanged outwards and riveted to the top, bottom and side panels. A strip of thin sheet tin has been inserted

between the panels, and the joint has been reinforced with strips of aluminium. The appearance of a longitudinal section through a portion of this joint is reproduced in Fig. 8.

The method adopted to secure the steel rod stays to the tank shell appears to be unduly complicated, and is shown in Fig. 9, in which the appearance of an etched diametral section through the coupling is reproduced. The successive laminations clamped within the rivets, commencing from the outer surface are :—

(i) Mild steel sheet, 20G.
(ii) Aluminium sheet 20G.
(iii) Sealing lamination of tin, of varying thickness.
(iv) Tank wall.
(v) Sealing lamination of tin, 0·012 in. thick.
(vi) Heavy gauge aluminium alloy forging or stamping.
(vii) Aluminium alloy channel.

The steel stiffener which appears dark, due to etching, is threaded at the end and two pairs of nuts and washers serve to secure it to the double cup formed by items (i) steel sheet, and (vi) aluminium alloy forging. A small inverted cup in mild steel sheet is placed over the end nut and a filling of tin-lead solder is finally applied to give a flush and petrol-tight surface finish.

The suspension bolt bosses such as the one at the outer end of channel C3 (Fig. 7) consist of an internally threaded tube, 3 in. long × 1¾ in. outside diameter, blanked off at the inner end by a steel covering plate, welded in position. A flange around the tube at about an inch from the outer end serves the same purpose as the light alloy stamping in the joint previously described—i.e., to secure the member to the tank wall.

### Corrosion Tests

The interior of the tank appears to be reasonably free from superficial corrosion. Marked external corrosion has developed on the front and rear panels of the tank, in those areas that have been coated with the adhesive used to secure the self-sealing covering. The regions along the riveted joints which have been coated with black celluloid resin compound appear free from corrosion. Microscopical examination of sections shows that the corrosion is of the intercrystalline type and has penetrated to a depth of 0·010 in. maximum—i.e., to about one-third of the sheet thickness.

In view of this feature, samples of the various light alloy sheet components were subjected to the accelerated corrosion test which consists of immersion in a solution of sodium chloride acidified with hydrochloric acid. Exposure for 24 hours was sufficient to confirm the high susceptibility of the front and rear panels to corrosion. Slightly lower susceptibility was noted for the other sheet materials. A sample of a channel shows no susceptibiity.

It is known that susceptibility of Duralumin to intercrystalline corrosion is caused by various unsuitable forms of heat-treatment—viz., comparatively slow cooling from solution heat-treatment temperature or reheating to 130° C. or over during or subsequent to age-hardening.

### Self-sealing Covering

Both fuel tanks have the same type of self-sealing covering consisting of the following layers of rubber and fabric, commencing with the innermost layer :—

(1) Layer of light-weight canvas cemented to the tank with gelatine hardened with a chromate. This canvas is probably used to prevent any petrol leaking from the rivet holes, from damaging the self-sealing covering.

(2) Three-ply sandwich consisting of an inner layer of red sponge rubber (approximately 7·5 mm. thick), a layer of vulcanised rubber sheet (approximately 0·8 mm. thick), and an outer layer of 3 × 1 cotton twill rubberised on the outer surface. These three layers are cemented together, but not to the inner layer of light-weight canvas. This sandwich only covers the lower half of the tank, and is held in position by cord straps which pass over the top surface of the tank.

(3) Two-ply sheet, consisting of an inner layer of red sponge rubber (approximately 7·5 mm. thick), and an outer layer of vulcanised rubber sheet (approximately 0·8 mm. thick). These two layers are cemented together, but the sheet is not cemented to the previous one.

(4) Three-ply sandwich, consisting of an inner layer of red sponge rubber (approximately 7·5 mm. thick), a layer of vulcanised rubber sheet (approximately 0·8 mm. thick), and an outer layer of blue American cloth. This sandwich is not cemented to the previous one. The outside layer of American cloth is treated with a cellulose dope on the outer face, to protect the self-sealing covering from petrol spillage.

The total thickness of the covering on the lower half of the tanks is approximately 26·5 mm., and the weight per sq. ft. is 1·0 lb. The corresponding figures for the upper half of the tanks are approximately 17·0 mm. and 0·6 lb.

This self-sealing covering is similar to the " Semape " system used on several types of British aircraft, the main difference being in the fabrics used and the fact that the layers of sponge are only backed on one side with vulcanised rubber sheet instead of on both sides, as in the " Semape " system. Both these factors appear to be detrimental from a self-sealing point of view. The thinner fabric gives less support to the self-sealing covering, and the single backing of vulcanised rubber sheeting to the sponge rubber allows a larger area of sponge to be affected with petrol from bullet wounds.

Firing tests have been made with 0·303 in. armour-piercing ammunition on a tank of similar construction and with the same sealing covering. The results of these tests show that the protection provided by this covering is much inferior to that obtained with the Semape self-sealing covering.

### Mounting of the Tanks

The forward fuel tank is normally fixed in the fuselage immediately behind the fireproof bulkhead. Four bolts secure the tank to the tubular members forming part of the fuselage structure. The rear fuel tank is fitted into the fuselage immediately aft of the forward one, and held in position by four bolts which are screwed into the tubular members forming the fuselage structure. The two tanks are separated by an open framework made of tubular steel members.

Removal of these tanks for repair appears to offer considerable difficulty, as the supporting bolts appear to have been inserted before the thin metal skin of the fuselage has been fitted. In order to remove either tank, part of the fuselage skin would have to be removed first. This would not be too easy, as the skin is riveted in position. As the tanks are fairly well protected from frontal attack by the radial engine and from rear attack by the main body of the fuselage, it is probable that these tanks are not unduly vulnerable.

### Drop Tank (Focke Wulf 190)

The drop tank carried by the Focke Wulf 190 is also constructed of light alloy, the shell and six baffles being made from 14G sheet. The maximum diameter of the tank is about 1 ft. 8½ in. All inserts, baffles and pipes have been welded into position in the outer casing. The only surface treatment which has been given to the material of the tank is a coating of blue paint on the outer surface of the shell. The tank has a capacity of 65 gals.

### Chemical Composition

The materials of the shell and baffles were chemically analysed. The results are given in Table VIII.

TABLE VIII.

CHEMICAL ANALYSES OF SHELL AND BAFFLE MATERIALS.

| | Baffles. % | | Shell. % |
|---|---|---|---|
| Copper | 0·03 | .. | 0·02 |
| Silicon | 0·12 | .. | 0·14 |
| Iron | 0·31 | .. | 0·33 |
| Titanium | 0·03 | .. | trace |
| Magnesium | trace | .. | trace |
| Manganese | trace | .. | trace |
| Zinc | nil | .. | nil |
| Nickel | nil | .. | nil |
| Aluminium | Rem. | .. | Rem. |

The above figures show that both the casing of the tank and the baffles are made of commercially pure aluminium.

### Tensile Tests

Tensile tests were made on specimens taken from one of the baffles and the outer shell of the tank. The results are given in Table IX.

TABLE IX.

TENSILE TESTS ON SAMPLE SPECIMENS.

| Position of test | Baffle. | Shell. | |
|---|---|---|---|
| Direction | — | Longitudinal. | Circumferential. |
| Width, in. | 0·251 | 0·249 | 0·249 |
| Thickness, in. | 0·076 | 0·075 | 0·077 |
| Limit of proportionality, tons/sq.in.$^2$ | 2·5 | 3·6 | 1·4 |
| 0·1% proof stress, tons/sq. in.$^2$ | 5·8 | 6·0 | 5·1 |
| 0·2% proof stress, tons/sq. in.$^2$ | 6·3 | 6·5 | 5·7 |
| 0·5% proof stress, tons/sq. in.$^2$ | 6·7 | 6·8 | 6·1 |
| Maximum stress, ton /sq. in.$^2$ | 6·9 | 6·9 | 6·4 |
| Elongation on 1 in., % | 10·0 | 11·0 | 11·0 |
| Young's Modulus (E) $\div 10^{-6}$ lb./sq. in.$^2$ | 10·1 | 12·6 | 10·0 |

The above results indicate that the material is in the condition as rolled and that it has received no annealing treatment.

### Microscopical Examination

Sections taken through various weld joints were microscopically examined. The adhesion between the materials appears to be good in each case and the welds quite sound.

### Conclusions

Both the outer shell and baffles are constructed of sheet material in commercial aluminium of about 99·5% purity. The material has an average tensile strength of about 6·8 tons per sq. in., and an average elongation value of 11% in tensile test. These values indicate that the material has not been annealed after rolling. Commercially pure aluminium appears to have been used, because of its good corrosion resistance and ease of fabrication. Microscopical examination shows that the material has been satisfactorily welded.

## The Institute of Physics

THE annual report of the Institute of Physics, which has just been issued, once again reflects the important contributions to victory which are being made by British physicists, and records plans which are now being made so that this young profession can continue its vital service for the development of our industries when hostilities cease. In particular, the Board of the Institute has given consideration to the position of physicists and those desiring to enter the profession during the demobilisation period. It is in touch with the Government on these matters, and through the Joint Council of Professional Scientists, is co-operating with qualified scientists practicing in other branches of science, such as Chemistry, Biology and Geology.

The Institute's report on the Education and Training of Physicists, which was one of the first of its kind to be issued, was very well received, both at home and overseas. Active steps have already been taken to follow up the recommendations contained in it. Thus the report making recommendations for changes in the method of teaching mathematics to prospective physicists, which has been prepared by a Joint Committee of the Institute and the Mathematical Association, after a lengthy study of the problems involved, is about to be issued, and the inquiry into "the possibility of including the various branches of technical physics within the framework of National Certificates and Diplomas" has made good progress.

The report records the many technical meetings held by the local branches at home and overseas, and by the subject groups.

At the recent annual general meeting of the Institute of Physics, held on Monday, May 22 last, the following were elected to take office on October 1, 1944:— President: Sir Frank Smith. Vice-Presidents: Prof. J. D. Cockcroft, Mr. T. Smith, and Dr. F. C. Toy. Hon. Treasurer: Major C. E. S. Phillips. Hon. Secretary, Prof. J. A. Crowther. Ordinary Members of the Board: Dr. H. Lowery, Prof. N. F. Mott, Prof. E. A. Owen, Dr. C. Sykes, Mr. R. S. Whipple, and Mr. C. S. Wright.

## Joint Conference on Instruments for the Automatic Controlling and Recording of Chemical and other Processes

THE Institution of Chemical Engineers and the Institute of Physics announce a joint conference on "Instruments for the Automatic Controlling and Recording of Chemical and Other Processes." Provisional arrangements have been made for the conference to take place in London on Friday afternoon, September 22, and Saturday morning, September 23. The purpose of the conference is to promote the interchange of knowledge and experience between those employing automatic controllers and recorders in different fields and to encourage collaboration between physicists and chemical engineers.

Further particulars will be sent, in August, to those sending a request for them to the Organising Secretary, Joint Conference, c/o the Institution of Chemical Engineers, 56, Victoria Street, London, S.W. 1.

# Malleable Cast Iron

## Part I.—Historic Outline of Malleable Cast-Iron Industry

By J. A. Wylde

*Where strength, ductility, machinability, and resistance to shock are important considerations, malleable iron castings find a wide field of industrial applications. The application of scientific principles to everyday practice by responsible malleable iron founders has done much to establish confidence in these castings for uniformity in high tenacity and ductility. In this the first of a series of articles on the subject, a brief historical outline is given of the development of Whiteheart and Blackheart malleable castings.*

HISTORIC facts about the birth and particularly the development of the malleable cast-iron industry are few and far between. Apparently in the early days of the industry it received little attention from the metallurgists, or, perhaps, on the other hand, the metallurgists' attention may not have been welcomed by the founder.

From the brief facts that are available, the pioneers of the industry seemed to have worked very much in the dark. It matters little whether their results were obtained by a combination of hard work and good fortune. We can only pay tribute to these men whose sincere endeavours laid the foundation of this very important branch of foundry-work. The industry, even up to recent times, was shrouded with a cloak of mystery, and the work went on literally behind closed doors. It is known that in America and this country the responsibility of the melt often lay in the hands of men quite unversed in metallurgy. In some foundries the decision as to whether the metal was suitable for casting was made by a leading moulder, although he might be quite unable to say why such was the case.

The foregoing remarks are made to indicate the lack of scientific control in early malleable casting production and to make a contrast with the great strides which have been made in the industry in the last few years.

For the purpose of this series it is essential to deal with the two types of malleable cast iron which are produced—namely, "Blackheart" and "Whiteheart," but before dealing direct with malleable cast-iron development, it will be of interest to mention briefly the early history of iron production generally.

Traces of the commercial use of iron, probably in a crude form, have been found dating back to the time of the Egyptians, and references are made in the Bible to the manufacture of articles in iron. One very fine example of the ancient ironworkers' craft may be cited in the Delhi Pillar, said to have been erected about A.D. 300. Due to its extreme lack of impurities it has withstood the ravages of corrosion. It is known also that the ancient Greeks made steps in the development of iron production. They introduced a crude type of furnace with a stack, charging the fuel and ore in layers. This crude furnace was the forerunner of the blast furnace and cupola as known to-day.

It was not until the fourteenth century, however, that the first known blast furnace was established in Western Europe, when Leonardo Da Vinci (1452–1519), Italian artist and scientist, introduced blast for smelting iron.

The next development of note which concerns us here was the introduction of the cementation process during the fourteenth and fifteenth century. This process consisted of heating in contact with charcoal, bars of soft wrought iron produced from ore. This cementation process produced an inferior type of steel, the wrought iron being recarburised by the action of the charcoal. The resultant steel was not particularly homogeneous, having been produced from wrought iron made direct from the ore. Further advances were later made by melting the recarburised steel in crucibles, thus producing a material of increased homogeneity.

Due to the curtailment of wood fuel supplies there was a falling off of iron production in this country during the sixteenth century. Another fuel was looked for, and a name worthy of mention in this connection is that of Dud Dudley, a Staffordshire man. About the year 1620 he attempted to melt with pit coal. Dudley's efforts in production did not equal those obtained with the use of charcoal. It is also claimed that a good sound iron could not have been produced with raw fuel and the primitive furnaces of that time.

Ironfounders had to wait until the beginning of the eighteenth century for the introduction of coke as an economical melting fuel. The introduction of this fuel, together with improved blast furnaces, eventually did a very great deal towards speeding up the development of iron and steel industry.

Although the discovery of coke fuel had proved itself to be of such importance, the bulk of the pig iron was still smelted by charcoal in this country for some 60 to 70 years after the introduction of coke about the year 1730.

To generalise, we may say that there were in existence at the beginning of the eighteenth century three types of commercial iron, namely :—

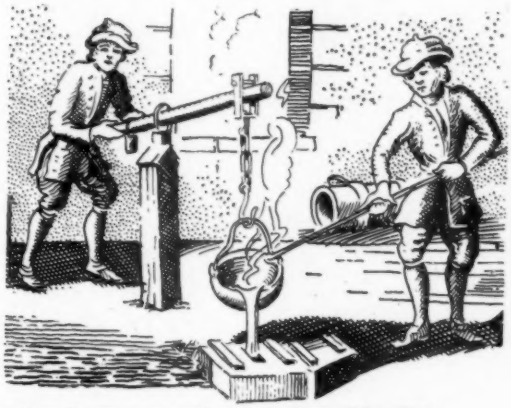
(1) Soft wrought iron produced direct from ore.
(2) Hard and brittle cast iron produced in the blast furnace direct from ore.
(3) Crucible or cemented steel produced from wrought iron.

The last-mentioned material was of sufficient hardness to be used as edged tools and weapons.

As both wrought and cast iron could only be produced direct from the ore, the quality of both materials remained somewhat inferior, due to the unavoidable inclusion of impurities in the metal. Although iron was available in the three forms mentioned, the problem of producing a material possessing the malleability of

wrought iron, and the ability to conform to intricate shapes as with cast iron, still remained unsolved.

Reaumur, the French chemist, who was interested in the cementation process, probably followed the line of thought that if wrought iron could be hardened by recarburising, a hard brittle cast iron could be softened by an adverse process of carbon extraction. (Oxygen was not known then, being discovered in 1774 by Joseph Priestley.)



**Sketches showing interior views of Reaumur's foundry, taken from a reproduction of an old print.**

In the year 1722 Reaumur introduced a process for softening iron castings by the extraction of carbon without re-melting. The process consisted of heating the castings at red heat in contact with powdered ore for many days. This process of oxidation forms the basic principle of the "Whiteheart" process of to-day. Reaumur's process was revolutionary in cast-iron production, and was the foundation upon which a very considerable industry has been built.

To-day it can be fully realised the great difficulties this early pioneer had to contend with, especially in the nature of inconsistent raw materials.

It is known that one of the most important factors governing malleable casting production is the use of high quality pig iron of consistent analysis. The material Reaumur had at his disposal was of high sulphur and low manganese content which, no doubt, caused him much concern when "annealing" the castings. It should be pointed out here that there were limitations to the application of Reaumur's process which still exist in a lesser degree with the production of Whiteheart castings. As the malleablising process was one of oxidation, varying degrees of softness in the "annealed" casting would obtain, except in the case of those of very thin section where almost complete malleabilisation would take place. In the case of castings of fairly robust section, the outer skin would be nearly pure ferrite, growing harder towards the centre where the oxidising influence of the ore had not penetrated and the carbon remained in its original combined state.

From the foregoing it will be appreciated that only castings of uniform light section could be treated with any degree of certainty. Upon obtaining results which produced castings of varying hardness towards the centre of the heavy sections, the tendency was to prolong the period of anneal, but with disastrous results. Efforts to completely "anneal" heavy castings only resulted in the lighter sections becoming extremely over oxidised and the whole surface of the casting being scaled and rendered useless.

Although Reaumur may be regarded as the father of malleable cast iron, it was his belief that iron of a quality equal to Swedish iron could be produced in France, in spite of the inferiority of French ore. Due to this belief, his country expended much time and money to no good purpose. Following the discovery of the malleablising process attributed to Reaumur, the industry began to grow steadily in Europe. Eventually, knowledge of the process began to drift into this country, possibly due to the migration of workmen.

In the year 1804 a process for "separating impurities from crude or cast iron without fusing or melting" was patented by a Sheffield founder, Samuel Lucas. This process was undoubtedly based upon the findings of Reaumur. It is doubtful whether malleable iron founding grew very rapidly in this country, in view of our somewhat natural caution, and probably also due to the fact that this process, in its early stages, was unreliable and only confined to small unimportant castings.

It is due to these early failures that malleable iron castings earned an unwelcome name for unreliability, and retained this reputation long after it was justified.

Following Reaumur, the main development of importance in iron production was the introduction of the "puddling" process by Cort, who took out a patent in 1784 for "converting pig iron into malleable iron."

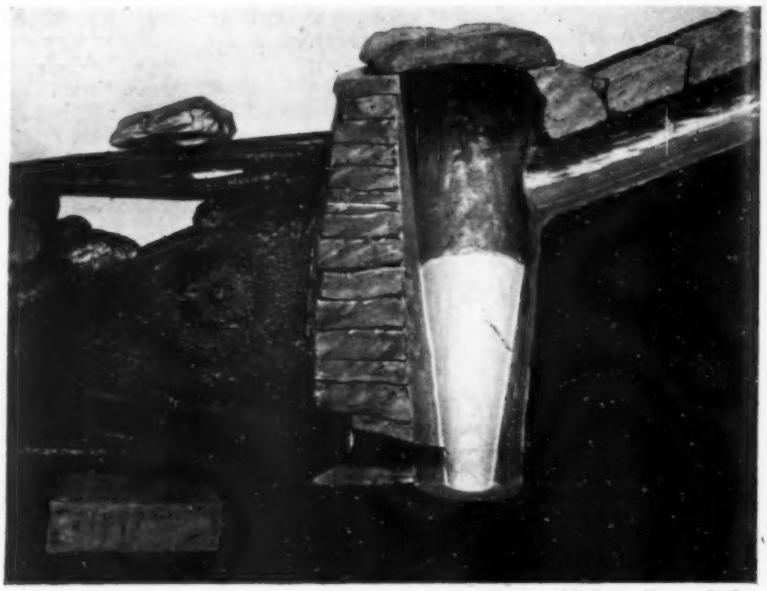
A word in season here will do much to fix the exact designation of the material we are discussing. "Malleable iron" is a term loosely used to describe malleablised castings, whereas the same term may equally apply to wrought iron. As the definition of wrought iron is "iron which is malleable," the correct term for the material under discussion is "malleable cast iron."

No progress of note has been recorded since Reaumur and Lucas, until America began to take interest.

Seth Boyden, a Bilston man who had migrated to America, was experimenting in 1826 with the production of malleable iron castings by the "European" or "Reaumur" process. Boyden was no scientist, but a practical foundryman, who had set up business as an ironfounder in Newark, New Jersey. He was probably most disappointed to find that the material he produced was dark in fracture instead of "steely," like the European Whiteheart. Boyden was striving to reproduce the European process with American raw materials.

The difference in the analysis of the two classes of raw materials was not apparent to him, and consequently, due to this variation, the annealing action was one of graphitisation instead of decarburisation. The raw materials used in Europe and England being high in sulphur and low in manganese and silicon, when heated in contact with an oxidising medium (powdered ore), the carbon burnt out of the carbide of iron. Whatever carbon was left in the castings after annealing remained in its combined state, together with the original chemical element. Boyden followed Reaumur's process, but the raw materials he used in the castings were low in sulphur and high in manganese, and, when heated with a view to decarburisation, carbon in the castings graphitised instead.

**Seth Boyden, drawn from an old photograph.**



*Courtesy of the Science Museum, London*

**Showing section of a primitive blast furnace as reconstructed in the Science Museum.**

In his failure to reproduce Whiteheart malleable cast iron from American raw materials, Boyden stumbled on a product of a far superior quality to Whiteheart. This product possessed all the good points of European Whiteheart and, in addition, was more consistent, simpler to anneal and more easily machined.

This discovery by Boyden marked the beginning of the production of " Blackheart " malleable cast iron, and the Blackheart child rapidly outgrew the Whiteheart parent, at least in America.

Although one of the main differences between the Blackheart and Whiteheart processes lies in the " annealing." This was not appreciated for many years after Boyden's discovery. Great importance was attached by early Blackheart producers to the packing medium, and its supposed effects upon the " annealed " castings. It was not realised until later that the Blackheart annealing process was one of graphitisation and not decarburisation and that a packing material rich in oxidising properties was not necessary.

Boyden's process began to develop quickly, and by the end of the nineteenth century the production of Blackheart malleable cast iron had spread rapidly through America, to the almost total exclusion of Whiteheart. When America's malleable cast iron output got into its stride, the total output of Europe and England looked insignificant. It must be appreciated that the malleable cast-iron industry in America started its growth in a country that was expanding, and Blackheart malleable offered a cheap material capable of being produced in large quantities. Furthermore, large deposits of fine quality ore were available.

It must be appreciated that a considerable number of small foundries were producing Whiteheart malleable iron castings in this country at that time with varying degrees of success, but little real attempt was made to improve their products, " rule of thumb " methods prevailed, whereas in America much research work was carried out to develop the Blackheart process.

In spite of favourable conditions, however, the enterprise of the American malleable founders is to be admired for the way in which the industry was developed. A great factor in its development being, of course, the motor-car boom. Large runs of castings were in demand, calling for a minimum of machining, ideally suited to production in malleable cast iron.

In this country the demand for Whiteheart cast iron was not great, and it was not until the cycle boom that this material came into any real prominence. From that time the industry began to improve and its members began to take a more active interest in the metallurgical aspect.

The material produced in this country up to the last 25 years (with the exception of one or two Blackheart pioneers) was Whiteheart, but, with the introduction of modern melting plants, metallurgical control and improved raw materials, the field of Blackheart producers is ever widening.

In consequence of the steady development of Blackheart malleable production in this country, the uses to which malleable cast iron can be, and is, applied increases almost daily.

America abandoned the crucible as inadequate and the cupola as unreliable long ago. The air furnace, the open-hearth and latterly the electric furnace and rotary

furnace took their place. Malleable cast iron, particularly Blackheart, is a metal which requires the best melting conditions possible. This fact is now well appreciated by discerning malleable ironfounders in this country. The policy of scientific metal control and first-class melting conditions British founders are developing to-day is being amply rewarded. Although for many years progress has been slow, the day is not far distant—or perhaps it is here—when this country's malleable cast-iron products will be second to none.

*(To be continued.)*

# Correspondence

## Gold and Silver Winning by Amalgamation

The Editor, METALLURGIA.

Dear Sir,

The articles by Dr. D. R. Hudson on " Gold and Silver Winning " have no doubt been read with great interest by those interested in ancient history. Personally, however, I was rather disappointed at the scant reference to the great wealth of Celtic golden antiquity. That the Celts were inordinately fond of gold torques and jewelled ornaments is amply proved by the large number in existence all over the world, but particularly in Europe. Diodorus, although an historian of the 1st century B.C., is comparatively modern regarding the known Celtic history of gold and its working. His writings show he was anything but pro-Celtic, although he records the Celts did not rob their churches. There is very little, if any, Roman influence on Celtic design, as the Romans never invaded Ireland, but instead built a wall to protect themselves from Celtic invasion. The Roman workings in Wales are also comparatively modern, being mostly A.D. The earliest reference to gold is found in the Bardic History, which says that in the days of Kings Bith, Lara, Fintan and Queen Ceasair, one taught the art of smelting and working gold. This ancient civilisation was annihilated by the great flood with the exception of Fintan, who changed himself into a salmon and went down to the sea. When the flood subsided, he came up one of the rivers and resumed his human form. There seems some evidence of the truth of the existence of the art, but the salmon part is doubtful. The art of working copper and bronze is also mentioned in Bardic History. An early belief was that the souls of the dead went to a far-off land.

> There is a distant Isle,
> Four feet uphold it,
> Feet of white bronze under it.

This is no vague mention of bronze, but a specific " white " bronze. Red bronze is mentioned in the third century in a description of King Cormacs' apparel, as follows :—

> A red buckler with stars and animals of gold and fastenings of silver, a torque of gold around his neck, a white shirt intertwined with red gold thread, a girdle of gold inlaid, with precious stones. Two shoes of gold with golden loops, two spears with golden sockets, with many rivets of red bronze.

Another reference to bronze in Bardic History is as follows :—

> Golden chariots on the sea plain,
> Rising with the tide to the sun;
> Chariots of silver in the plain of sports
> And of unblemished bronze.

Like most history, actual dates are more or less conjecture, but with a basis of fact. King Tigernmas is mentioned as one of the earliest miners of gold in the Wicklow Hills, Sir Flinders Petrie found undoubted

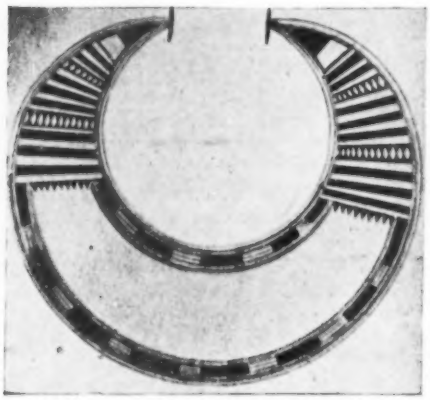
**The Tara Brooch.**
**Bronze, gold filigree, settings of amber, enamel and glass. About 700 A.D.**

**Shrine of St. Patrick's Bell.**
**This decoration consists of enamel, gold filigree work and crystals. It dates from the 11th century.**

**The Cross of Cong.**
**A Processional Cross, made between 1123 and 1136.**

Irish gold ornaments in tombs at Gaza, reputed by him to be 4,000 years B.C. I do not know of any attempt to correlate any of the ornaments to their source of supply by analysis, and it is easy to understand the reluctance to submit them to this process, but in these days of micro-analysis, I should think something could be done.

Notes on the composition of ancient Irish gold and silver ornaments were published by Ernest A. Smith, Assoc.R.S.M., etc., in the R.I.A. Transactions, May, 1896. I have not seen them, but he states therein that no other country in Europe possesses so much manufactured gold belonging to early and mediæval times. Dr. Hyde



**Gold Lunula.**

**Probably dates from 2000 B.C.**

mentions in his "Literary History of Ireland," that pre-historic gold in the British Museum was about three dozen ounces, whilst that in the Dublin Museum amounted to five hundred and seventy ounces. Since then it has been added to. In 1940 a turf cutter found an oak box containing four gold bracelets estimated to be 800 B.C. There is no doubt that Irish gold ornaments found their way to the East by trade with the Phœnicians, as Tacitus reports that Irish harbours were better known through trade than those of Britain.

A final interesting link between ancient and modern is the following: In 1893, a man ploughing in a field near Limavady by Lough Foyle, turned up some lovely golden ornaments, including a gold boat complete with mast and oars. After passing through various hands, the find was purchased by the British Museum. In 1903 action was taken by the Royal Irish Academy to recover the treasure. Sir Edward Carson was one of the counsel for the Irish side. The British Museum claimed that the treasure was a votive offering to the sea god Manannan mac Lir and was thrown into the sea about 1,000 years B.C., when this region was under the sea. Doctors Praeger and Coffey were commissioned to survey the scene and proved that the cliffs of Ireland were as high 1,000 B.C. as they are to-day. The Royal Courts of Justice decided that the treasure was not a votive offering to the Irish Neptune, and the judge described the B.M. claims as fanciful suggestions more suited to the poem of a Celtic bard than the prose of an English Law Report. The treasure rests in Dublin Museum to-day. This may be an interesting side-light on the antiquity of gold working in our own islands (even if not a very scientific one) to many of your readers.

I beg to acknowledge the help received from the writings of Dr. Douglas Hyde, Standish O'Grady, Aodhde Blacam, and the illustrations from Saorstat Eireann, which although not exclusive are the finest I have seen.—Yours faithfully,

GEORGE F. LARKIN (M.I.S.Inst.).

Essex House,
Farndon Road,
Newark, Notts.,
May 26, 1944.

## The Future of the Aluminium Industry

The Editor, METALLURGIA.

Dear Sir,

I have read your contributor's comments on my article in last month's issue of METALLURGIA, and I must protest against his assertion that I have attempted to conceal the importance of fabricating costs in the price of light alloy products. On the contrary, I entirely agree with him that the price policy of the fabricating industry is quite as important as the price of primary metal. What I did try to point out was that before any industry can give prices for its products, it must know what is likely to be the cost of its raw materials. Surely this is just ordinary common sense.

I also tried to point out that while it is quite clear that the fabricating industry, owing to its tremendous war-time expansion, will have the strongest incentives to pursue a vigorous expansionist policy in peace-time markets through the medium of keenly competitive prices, it is not at all clear that similar incentives will motivate the policy of the domestic producers, since there can be no doubt at all that, after the war, as before, there will be a ready market for every pound of metal that their limited capacity can produce. I am not unmindful that the great production of low-cost aluminium in Canada may supply the necessary incentive, but this is an aspect which, as I pointed out in a previous article, involves decisions at Government level, and on which therefore I prefer not to comment.

There is another point which I would like to take up with your contributor and that is the question of the price given for medium gauge Duralumin sheet. His figure of 2s. 6d. per pound is very wide of the mark, the actual price being about 2s., and in this connection we must, in fairness, also allow for the very substantial rebate which the industry pays to the Supply Ministry. Thus, it will be seen that my figure of 30% and your contributor's figure of 50% reduction will amount to practically the same thing.

Finally, I would point out that your contributor's statement that aluminium circles were sold before the war for less than 1s. per pound does not agree with the published price which in 1938 was 1s. 3d.—that is, 5d. per pound more than the price of aluminium ingot, instead of less than 2d. per pound which his figure works out at.

I am prepared, however, to believe that your contributor's figure may be correct, since the producers of pure aluminium were the principal rollers of pure aluminium sheet and could afford therefore, without offending the Cartel, to forgo some of the very comfortable margin which they must have had on the metal sold to the fabricating industry.—Yours sincerely,

W. C. DEVEREUX.

High Duty Alloys, Ltd.,
Slough, Bucks.
May 31st, 1944.

The Editor, METALLURGIA.

Dear Sir,

His letter of May 31 shows Mr. Devereux to be in agreement with me concerning the main factors at present influencing the development of the aluminium industry after the war. If I misconstrued the brevity of his reference to the price policy of the light alloy fabricators *per se*, I am sorry.

The situation can be summarised as follows :—

1. The present controlled price of virgin aluminium here is approximately double the price at which it is proposed that American metal should be supplied after the war.

2. The output of the British Aluminium Company is not sufficient to satisfy the domestic demand. Thus any reduction in price could be of no benefit to them since their sales would not be increased beyond their capacity to produce.

3. The wrought light alloy group has failed to give an indication of the probable post-war trend of their prices. They could do so by making a substantial reduction in the large margin between current costs and list prices. The amount represented by this margin is now refunded to the Supply Ministry after allowing a profit of approximately 12% on the capital employed, but list prices remain at about pre-war level.

As regards 1, it is clear that the profits of the British Aluminium Company can be maintained only if the price of metal is kept as high as would restrict consumption to the Company's economic production level. There is, of course, the possibility that the Americans would no longer subscribe to any price or quota agreements, especially as they were recently involved in anti-trust law litigation. If the market were free metal from North America could probably be landed here and sold profitably at a figure well below the actual cost of the domestic product. In the past, however, it was agreed by the Cartel that the British Aluminium Company should decide the price policy for this country.

It is of interest that the British Government has a vested interest in the extensions recently made to the Arvida reduction plant. As is the case with many extensions to factories paid for out of public funds, the owners of the parent plant probably have an option to purchase the additional equipment, but there is the possibility that it might be used in some way to link American interests in Canada with those of our domestic producers.

To conclude, it is obvious that the fabricating trades cannot support an inflated virgin metal price, but for their part they should demonstrate their confidence in their own industry by giving an indication of policy now. Their post-war costs cannot be forecast precisely but sufficient data are available to form the basis of a fairly accurate estimate.—Yours sincerely,

YOUR CONTRIBUTOR.

London, W. 1.
June 11, 1944.

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# Beryllium Oxide

By L. David, M.Inst.Met.*

USE has been found for beryllium oxide in various industries, especially in the electrical industry, for filament and heating embedding purposes, filament coatings in lamps, electrodes in electron tubes, and as a cathode heating element in radio tubes. It is also used in electrical heaters in which the resistance wire is embedded in the refractory. Because of its high resistance to thermal shock it is useful as a radiation shield around graphite crucibles. Special purpose crucibles and other refractories are also made from beryllium oxide.

A study of the strength of ceramic materials shows that above 1,400° C. beryllium oxide has a higher strength than $Al_2O_3$, $ZrO_2$, $ThO_2$ or synthetic Mgo $Al_2O_3$.[1] Ceramic products of beryllium oxide which are entirely gas-tight at 2,200° C. were advertised by a German firm in 1936, and it was claimed that they are hardly attacked, even at high temperatures, by carbon monoxide or hydrogen. They resist molten alkalies and do not react with carbon, carbon monoxide or hydrogen, but are very susceptible to acid attack.[11]

Highly sintered beryllium oxide is characterised by its great hardness and by good electric insulating and thermal conducting qualities at high temperatures, which qualities are of special importance when this material is used in the form of cores, rods or plugs to prevent heater-cathode-leakage in wireless valves. In addition, the comparatively light weight of beryllium oxide is of great importance.[1]

*Beryllium Smelting Co., Ltd., London, W.C.2.

The highest working temperature for alumina ware of best quality (recrystallised 99·9% pure $Al_2O_3$) is about 1,900° C., whereas the highest working temperature for beryllia ware (high-fired material) is about 2,400° C. The melting-point of beryllium oxide is 2,570°, which is approximately 500° C. higher than that of alumina.[2]

Beryllium oxide as generally used is light and fluffy, and has been passed through a 20-mesh screen, average density 16·2 lb. per cub. ft., calcined at about 1,450° C. The density measured on the bulk of the material, not packed, varies with the particle sizes. In 20-mesh material it is between 1 and 1·2 and gets progressively lower and finer with the mesh size. The true specific gravity of beryllium oxide is 3·02. This grade contains a minimum of 99·8% BeO after the slight moisture content has been removed. The maximum amounts of any one impurity in the oxide are approximately as follows :—CaO, 0·02% ; $Al_2O_3$, 0·02% ; $SiO_2$, 0·05% ; Su, 0·01% ; $Fe_2O_3$, 0·05%.

The contents of alumina, silicon and iron vary mainly with the amount of very small pieces of firebrick and rust present in the oxide. The particles enter the oxide when the salt (beryllium sulphate) is fired in a rotary furnace. The beryllium oxide itself generally contains less than 0·01% $Al_2O_3$ and 0·005% $SiO_2$. The $Fe_2O_3$ content is generally less than 0·03%, and the CaO content less than 0·01%. The oxide is tested for alkalies and impurities in general by heating a small sample at 1,650° C. for 15 mins. in an atmosphere of hydrogen. Only slight sintering, if any, should occur

from this heat-treatment. Qualities with lower (down to 1,200° C.) and higher (up to 2,000° C.) calcination temperatures are also used.

### Mesh Size

To obtain a finer mesh size, grinding in the usual porcelain or steel ball mill with sufficient alcohol will give the required material which can easily be dried in glass trays in a low-temperature oven.

Beryllium oxide is easily fluxed by relatively small quantities of calcium oxide and alkali metal oxides as well as fluorides. None of these is employed in the process described later on. Caution must be used throughout to avoid contamination from dust and the like.[1]

The procedure of manufacturing crucibles and refractory forms is described later on. Articles from beryllium oxide may be extruded or pressed with binders such as nit ocellulose or without binders.

From tests made in 1928 and 1930, it appears that addition of beryllium oxide to glass shows some possibilities. The hardness of glass is greatly increased by addition of approximately 1% of beryllium oxide and will exceed the hardness of soda-lime glass and magnesium glass. The mean hardness of glass containing 1% beryllium oxide is given as 6·400. It appears possible to manufacture low beryllia-high silica and high beryllia-low silica glasses with potash. Raw beryl which usually contains 10–11% BeO could be used for glass-making. This, however, would introduce alumina and some iron oxide.[6]

In order to increase density and shrinking for some purposes, silica or magnesium silicate can be added to the beryllium oxide. It can then be treated or sintered at around 1,600° C. The shrinkage effected and the increase in density will of course depend on the amount of silica added. For this purpose, the mixed sintered material is ground in a ball mill and approximately 15 hours' grinding will be sufficient to obtain material to pass a 200-mesh screen. In order to make a spray coating, 100 grms. of the ground material mixed with 200 ml. of a solution of nitrocellulose are mixed in a ball mill for 2 hours and is then applied by spray gun.[4]

Another binder is used for the manufacture of wireless mounts. Here, aluminium in powdered form is added to nitric acid. The resultant mixture which has the apparent characteristics of hydrolised nitrate of aluminium, is dried to produce a clear, non-crystallised substance. This solid is dissolved in alcohol or water to which beryllium oxide is added, and this paste is applied to the completed mould and is allowed to dry naturally or by heating.

Beryllium oxide is also notable for its large infra-red and blue radiations at elevated temperatures. From tests made in 1928 with cathode ray heating, it appears that the values of relative brightness on the blue part of the spectrum are as follows :—Brightness temperature : 1,500 K., 0·23 ; 1,700 K., 2·1 ; 1,800 K., 5·3 ; 1,900 K., 12·1 ; 2,000 K., 25.

At temperatures exceeding 1,700° K., the value for beryllia is considerably higher than for other incandescent oxides tested at the same time.[5]

Beryllium oxide is therefore used in incandescent lamps as a coating to increase the light and life efficiency of the filament and to reduce vaporisation, especially in the presence of gas pressure. The light radiating properties of this material are more selective to visible radiations than tungsten or molybdenum alone. For this purpose, generally two intermediate coatings which will make a thickness of approximately 0·01 of a millimetre are applied to the filament. They are made of a finely ground beryllium alumino-silicate mixed with ammonium borate in proportion of three to one with sufficient water. These coatings are dried by passing a current of about 1½ amp. through the wire. The outer layer is obtained by five coatings of beryllium oxide which has been ground and mixed with 25% by weight of ammonium borate and water added to the desired consistency. These coatings are dried and heated to about 500° C., at which temperature the ammonium borate decomposes, and they have enough consistency to allow the coated wire to be bent, welded, etc. A collodion coating can be applied where moisture absorption during storage should be avoided. The exhausting temperature of the lamp usually around 2,000° C. will cause the inner layers of beryllium-alumino-silicate to fuse with the resistance wire and form a dense, hard, flexible coating substantially integral with the wire, whilst the outer layer of beryllium oxide will withstand temperatures up to 2,400° C. and will therefore remain unaffected by the exhausting temperature.[7]

In the case of gaseous electron tubes, high vacuum and other types of tubes having a control electrode subject to secondary emission, coatings of beryllium oxide are also used to prevent secondary emission. In this connection, a 2% beryllium containing nickel alloy has been used. This alloy, when heated in the air, produces a surface layer of nickel and beryllium oxides. Subsequent heating during the exhausting process by high-frequency current reduces or vapourises the nickel oxide and leaves a film of pure beryllium oxide.[8]

### Production of Crucibles and Accessory Parts

In one process, pure unfused beryllium oxide is heated to 1,800° C. in a graphite container by means of a high-frequency induction furnace. The calcine oxide is then heated to about 1,100° C. in oxygen to remove any carbon either combined or in discrete particles, and then broken up and ground in a steel ball mill to pass a 200-mesh screen. This material is treated with chlorine to remove iron and is then washed with distilled water. The crucibles are formed by tamping the material moistened with a solution of beryllium chloride (4 g. of $BeCl_2$ in 100 ml. of water) into a graphite mould lined with a layer of paper. The interior of the crucible is formed by drilling with a properly shaped tool while the material is still moist. The mould containing the crucible is heated in air to about 1,100° C. for an hour. This enables the crucible to be slipped out of the mould. It is then placed on a tungsten sheet inside a graphite container and fired to 1,800° C. for 2 hours by means of an induction furnace. The crucible cover and cone above it are made separately in the same way, except that before finally firing to 1,800° C.[9] These articles also show very good resistance to thermal shock. This latter quality permits repeated heats to be made from the same crucible.[10]

Spectrochemical examination of iron ingots melted in alumina and magnesia revealed contamination from the refractory oxides, or by partial reduction of the refractory and solution of the reduced metal in the molten iron. However, ingots melted in beryllia were not contaminated. From the point of view of possible contamination of high-purity iron by the refractory, beryllia is preferable to magnesia or alumina. Beryllia

was also found to be preferable to the other two in the removal of silica during melting. The silicon content of some sponge iron was reduced from 0·027 to 0·007% by melting in a beryllia crucible, but similar melts in magnesia and alumina retained respectively 0·010 and 0·016% of silicon.

Melts of platinum were also made in one of these crucibles in the high-frequency induction furnace. The metal was allowed to freeze in the crucible and after removal of the button, except for a layer of volatilised platinum on the wall, it could hardly be seen that the crucible had been used. The experiment with beryllium oxide indicated that it does not volatilise as rapidly in contact with carbon at 2,000° C. as does magnesium oxide and that very satisfactory crucibles for high temperature service may be formed from it.[9]

The following information on the extraction of beryllium from the raw beryl will probably be of some technical interest to users of beryllium oxide and other compounds.

The literature generally states that powdered beryl is not attacked by any single acid except hydrofluoric.[12] Consequently, for " opening the ore " alkaline fluxing is generally resorted to, with accompanying introduction of alkaline metals which complicate the remaining treatment. Beryllium oxide in powdered raw beryl, however, may be 76% extracted by treatment at 265° C. with dilute sulphuric acid. This is considerably above the boiling point of the acid, and high pressure develops. But if the raw beryl is given a preliminary heating in a rotary kiln to temperatures above 1,000° C., its susceptibility to sulphuric acid is greatly increased. The higher the temperature of heating, the more ready and complete is the extraction. Beryl, which has been heated to its sintering point at about 1,450° C., yields 91% of its beryllium on treatment with 56% sulphuric acid at only 250° C. If the beryl is made hotter until melted and then quenched in water, it becomes very reactive with strong sulphuric acid at atmospheric pressure. After the beryl is quenched in water, it is no longer optically active between crossed nicols, nor does it give an X-ray spectrum. The original crystalline structure has therefore been destroyed to bring about the accompanying increase in susceptibility to sulphuric acid. The melting point of beryl is indefinite and varies with its origin, but generally lies between 1,500° C. and 1,600° C., which is well within the range of open-hearth melting. Autoclave treatment with sulphuric acid will open the possibility of utilising beryl heated only to the sintering point in a cement kiln; thus subsequent grinding will be greatly facilitated, and beryl can be utilised which has not been entirely cleaned from its gangue.[2]

After the ore is sulphated, it is passed through Dorr leaching machines to extract all soluble sulphates, including those of aluminium, iron and alkali metals, as well as beryllium. The remainder of the process consists in simple evaporation and crystallisation with dewatering in sugar centrifugals. Aluminium is crystallised and separated quantitatively as the ammonium alum by the use of excess ammonium sulphate in the strong beryllium sulphate mother liquors. The essential feature of the separation not heretofore recognised was the concentration of the beryllium sulphate in the hot mother liquor to such a point that the mother liquor would be just saturated, with respect to beryllium sulphate, at its final crystallising temperature, thus effecting a complete precipitation of the aluminium.[13]

The ammonium alum is recoverable in a high degree of purity and may be converted into anhydrous aluminium sulphate or aluminium oxide.[14] Beryllium sulphate recovered by this process is fed into a rotary kiln fired by natural gas and there decomposed to beryllium oxide at a minimum temperature of 1,450° C. Beryl occurs in the Argentine, Brazil, Canada, France, India, Madagascar, Scandinavia, Union of South Africa, United States.

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# Reviews of Current Literature

## Roll Neck Bearings

PART I.—DESIGN, CONSTRUCTION AND OPERATION.

THE importance of roll-neck bearings in the economic operation of rolling mills has frequently been emphasised and the question of instituting research on the subject was discussed by the Rolling Mill Research Sub-Committee of the Iron and Steel Industrial Research Council. The complexity of the subject was quickly recognised, and in May, 1941, the Sub-Committee decided to proceed with a preliminary examination of the subject, and to prepare a survey of the position based on a study of the published literature and on discussions with manufacturers and users of roll-neck bearings in both the ferrous and non-ferrous industries. The volume of information that has been collected in the course of the inquiry has rendered it desirable to issue a complete report in two parts. This report, therefore, forms the first part of the complete report, and it embodies the results of a study of available information on various types of roll-neck bearings, rolling mills, bearing materials, etc.

The extreme bearing pressures, the comparatively low rotational speeds, the difficulties of excluding dirt or mill scale and water used for roll-cooling, etc., and the complications used by shock loading, all tended to make the proper application of fundamental principles almost an insuperable task for the designer. It is therefore not surprising that in the early mills it was thought impossible to apply scientific principles in design, and considerable wear and high friction losses were accepted as inevitable. Since then the problem has been further complicated, because the types of mills, the wide range of products to be rolled, the variety of different designs, bearing metals and lubricants available, have constantly increased.

The frictional losses in roll-neck bearings can, in

consequence, be a very significant fraction of the total power of a rolling mill. Fortunately, experience has shown that improved bearing design has effected worthwhile economies, which are of peculiar importance at the present time when any saving in power is highly desirable.

This report brings together into a comprehensive statement the results of research work so far done in overcoming the difficulties encountered with roll-neck bearings. It is presented in eleven sections, which deal with types of roll-neck bearings ; economic and technical considerations governing the selection of the type of roll-neck bearing ; operating conditions of roll-neck bearings and considerations governing their design ; theory of lubrication as applied to roll-neck bearings ; bearing metals ; plain metal roll-neck bearings ; synthetic resin bearings ; Lignofol and Lignostone bearings ; fluid film bearings ; roller bearings ; and needle bearings. In addition, an Appendix deals briefly with roll-neck bearing trend in wide continuous strip mills. The volume is complete with a comprehensive bibliography and an adequate index.

The second part of this important treatise which will be published later, will deal with the experience gained in the operation of the bearings in the British ferrous and non-ferrous industries. The present volume is excellently produced, bearing in mind war-time restrictions, and should be invaluable to all concerned with rolling mills, whether as designers or as users.

By L. R. Underwood, D.Sc. (Eng.), Ph.D., A.C.G.I., M.I.Mech.E. ; Chief Engineering Officer, Technical Department, British Iron and Steel Federation ; published by the Iron and Steel Industrial Research Council, Steel House, Tothill Street, London, S.W. 1.

## Resistance Welding of Wrought Aluminium Alloys

ELECTRIC resistance welding includes spot and seam welding and butt welding. Of these, spot-welding is by far the most important—indeed, seam welding and butt-welding are scarcely used at present for the light alloys in this country. The greater portion of a recent booklet, published by the Wrought Light Alloys Development Association, therefore deals with the spot-welding process.

In recent years there has been a notable improvement in the consistency and quality of spot-welds in light alloys. This has been made possible by an increased knowledge of the factors affecting the quality of spot-welds, by the development of appropriate technique and methods of control, and by improvements in machine design and performance. This booklet of 60 pages is not intended as a complete survey of spot-welding of light alloys, but rather as providing reliable information f.om a production point of view. The different types of welding machine available are described and illustrated, and there is a short section dealing with the choice of suitable equipment. Attention is given to the design, materials, cooling and cleaning of electrodes. The importance of surface preparation is stressed, and particular attention is paid to the various recommended methods of cleaning the sheet and removing the oxide film. The chromo-sulphuric acid pickle and phosphoric acid solution are dealt with in detail.

Methods of assembly are briefly summarised, and there is a section on machine settings. It is not possible to detail the exact settings for particular materials at present owing to the different characteristics of individual machines and the peculiarities of particular jobs, but an indication is given of the range of settings for each type of machine. A set of diagrams illustrates the various defects to be avoided. The inspection procedure is also summarised.

Design considerations, including recommendations for minimum weld spacing and edge distance are also dealt with. It is apparent that spot welds should be taken into account by the designer in the early stages rather than regarded as substitutes for rivets. The booklet concludes with appendices summarising British Standard Specification 1138, the pickling of aluminium alloy sheets, and a selected bibliography, and is complementary to Bulletin No. 5, published by the Association, which dealt with the welding of wrought aluminium alloys by the gas and arc processes.

Information Bulletin No. 6, published by the Wrought Light Alloys Development Association, Union Chambers, 63, Temple Row, Birmingham, 2. Price 1s.

## The Better Use of Compressed Air

WE all know that compressed air, properly used, is a very convenient way of transmitting power and for doing a host of industrial jobs. But it is not, perhaps, generally realised that unless compressed air installations are carefully supervised and maintained they can be terrific wasters of fuel. Compressed air isn't hot, like steam, or inflammable, like gas ; so it is much more liable to be wasted than either steam or gas. All too often compressed air is flagrantly misused. It is then that the fuel wastage is greatest.

Air is cheap—until it has been compressed. Every opportunity should be taken to impress this fact upon operatives. Many seem to think that because air costs nothing, compressed air is just as inexpensive. How wide of the mark is this idea may be gauged from the fact that compressed air, at a pressure of 100 lb. per sq. in. leaking through a $\frac{1}{4}$ in. diameter hole wastes coal to the tune of at least 32 tons per year of 2,500 hours. Through a $\frac{1}{2}$ in. hole the loss would be four times as great. Granted a $\frac{1}{2}$ in. leak is pretty big and not likely to be overlooked for long. But a $\frac{1}{16}$ in. leak is easily overlooked, and 64 such leaks (not by any means an improbability in large installations) are equal to a $\frac{1}{2}$ in. leak.

This very important question of compressed air leakage is dealt with in a new bulletin just issued by the Fuel Efficiency Committee of the Ministry of Fuel and Power, and an extremely useful method of testing for leaks is included. Indeed, the bulletin is a very practical guide to the measures necessary for the efficient operation and maintenance of industrial compressed air plants, at least of the smaller type.

A clean and dry air supply at pneumatic tools and other appliances is essential. The removal of moisture from the system especially needs careful attention and is given an important place in the bulletin. The use of an efficient after-cooler between the compressor and the receiver is stressed. The air-receiver is the " fly-wheel " of the system, taking care of varying requirements, and the bulletin urges users not to stint money on this piece of apparatus.

Users of the smaller types of compressed air plant will find the bulletin extremely useful both as an aid to better operation and more economical running. It is Fuel Efficiency Bulletin No. 29 and copies can be obtained from your Regional Fuel Efficiency Committee.

# The European Patent Situation in the Immediate Post-War Period

By S. T. Madeley

*The reconstruction period after the war will create many problems, amongst which will be those concerning patents. The author discusses some of these problems and gives information which will be helpful to many readers directly concerned.*

AT the present time there is sitting a committee which has under consideration our Patent Act. The members include an eminent patent counsel, a past-president of the Chartered Institute of Patent Agents, two prominent industrialists who combine between them expert technological knowledge of chemistry, electricity and engineering, and an economist of academic distinction who is also a woman. Seemingly, therefore, the problem will be adequately attacked from all important angles. No doubt amongst the subjects for discussion will be the question of extending the scope of the compulsory licence section.

Obviously, the reconstruction period immediately after the war will be a subject requiring very careful forethought, although naturally a longer view than that will also have to be taken. In particular, foresight will demand that everything that fairly can be done shall be to encourage our inventive genius, which has raised us from a small, poor, agricultural community to an outstanding industrial nation and a dominant factor in the world of to-day.

## Patent Situation Immediately After the Last War

After the war of 1914-18 there was appointed a Royal Commission for Awards to Inventors which expended large sums in remuneration for those cases which had helped us to a successful issue to the hostilities. Yet the amount disbursed was none too much, having consideration for the expenses incurred in development of the inventions.

The Patent Act was amended to extend the patent term from 14 years (as it then was) to 16. Sub-section 6 was added to Section 18, whereby a patentee could apply for an extension of term on the sole ground of loss or damage due to hostilities. This provision does not apply to enemy patentees. By the Amending Act of 1942 extension was limited to 10 years.

During the war licences were granted under existing enemy patents. In the early days application from enemy nationals were received and fees might be paid, but grant was withheld. Then the patents were granted to the Custodian and by him licences were granted to manufacturers. Later enemy applications were no longer received, and the benefit of all existing enemy patents and enemy patent applications were invested in him. After the war he divested himself of these and restored them to those entitled to them.

Art. 306 of the Peace Treaty prevented German nationals from making claim against the Crown for use during the war and protected subsequent purchasers of the articles so used.

Royalties under the above-mentioned licences were payable to the Public Trustee for the benefit of German nationals. The limiting rights over industrial property acquired under the Peace Treaty were only to be employed as necessary for national defence or public interest. The Comptroller during the war could extend the time where necessary for patent procedure. A year from the coming into force of the Peace Treaty was allowed for paying fees, filing documents, performing actions and so on with regard to industrial property where the war had interfered with ordinary procedure. War-time infringers of German patents were protected by Sections 307, 308 and 309 of the Peace Treaty. For six months after the coming into force of the Treaty there might be claimed International Convention priority rights which had not expired on August 1, 1919, or had arisen during the war.

A large number of belated patent applications were filed in the United Kingdom after the close of the war.

Belgium gave seven years' extension of patent term in all cases, France up to five years, and Germany up to five years.

## European Patent Situation During the Present War

Different questions arise where, as in the U.S.A., patents when granted are not subject to renewal fees. Enlightened by its previous experience, our Government very soon after the commencement of hostilities issued the Patents, Designs, Copyright and Trade Marks Emergency Act, 1939, and sundry Statutory Rules and Orders relating to the same subjects.

The Emergency Act gives the Comptroller-General wide powers to grant emergency licences and to amend or revoke licences already existing under enemy-owned British patents, and generally deal with patent procedure in such cases. He also is enabled by that Act to grant extensions of time in relation to proceedings before the Office, where delay and so on has been caused by the war.

The Statutory Rules and Orders above referred to and their successors give the Government very wide powers indeed. Patent application could at first be filed and Patent Office fees paid on behalf of the occupants of Germany and occupied Europe generally, under the General Licence. When France fell out of the war the occupied portion came into the category as the rest of occupied Europe, whilst Vichy France formed a slow and uncertain channel of communication therewith, dependent on passes being obtainable. Later communication through Vichy was brought to an end.

The General Licence which came into force in April, 1942, practically severed patent communication between the belligerents. According to this licence, renewal fees on British patents wholly or partly owned by enemies, could only be paid by non-enemies who were licencees

under the patents. By an Order issued in December, 1942, exception was made in favour of members of the Allied States forming members of the United Nations who would not have been enemies but for the occupation by the Axis powers of the territories of the said States.

Patent fees could and can be paid to the various aforesaid Allied Governments in London. The French Patent Office, however, refuses to recognise such payments in respect of French patents.

Under the Emergency Act the Comptroller has power to extend the time for paying renewal fees in the case of patents which would have or may have lapsed owing to the inability of patentees to keep them in force owing to the war. Inevitably, some of these cases will remain to be dealt with after the war.

In cases of this kind now being dealt with, the Comptroller's practice is to add to the Certificate of Renewal provisions corresponding to those inserted in restored patents for the protection of those who have infringed during the expired period. They are set out in Sections 65 and 66 of S.R. and O., 1939, No. 858.

Section 65 provides for the compensation of innocent infringees during the void period. The Comptroller will, after hearing parties, assess the amount, if any. Payment can be avoided by allowing the patent in question to become void. Wise manufacturers will have taken emergency licences where desirable under enemy owned patents in force.

As regards pending cases, although patent applications are running at somewhere about half their pre-war number, the Patent Office is several thousands behind in its official examination as to novelty, and so on, owing to difficulties, such as shortage of staff. Furthermore, there are many prospective applications, for example, from France now in this country which cannot yet be filed because funds are not available to pay Patent Office stamp fees, and so on. The stimulating enforced exchange of information between manufacturers should increase the numbers of inventions in the United Kingdom for which protection will be sought.

For one reason or another a not inconsiderable number of inventors are holding up their applications until the post-war period, although they have come forward wonderfully when their ideas are for direct war value. We must reckon too with an increasing inflow from the neutral countries, whence the bottle neck of waiting difficulties had disappeared. Release from German grip will be sure to account for many applications from Occupied and Axis countries—the major part of Europe.

All these sources should therefore produce a large crop of post-war applications and, no doubt, rude shocks in not a few cases when the priority dates come to be considered. It goes without saying that the Patent Office will be, as always, absolutely just in these matters.

Apparently the Comptroller's powers under the present Act and S.R. and O. are sufficient to enable him to deal with the situation which seems likely to arise.

The above factors would appear to indicate, as regards pending and new cases, a terrific pressure of work, a numerically inadequate staff, and for some time very considerable delays in the issue of the results of the Official Search, accompanied by much initial uncertainty as to priority. When more people have time to attend to their patents, a considerable number of patents are likely to come up for extension under Section 18 (6 and 7).

An exceedingly important question is the attitude of the Government towards patents during the post-war reconstruction period. Under Section 29 of the Patent Acts they will be able to use what patents they desire for this purpose, referring to the Court or a referee or an arbitrator thereby appointed disputes as to the making, use, or exercise of an invention or the terms therefor.

One may expect the Government to use its powers with vigour.

Many inventors and patentees will probably not feel satisfied unless their claims to post-war remuneration are dealt with on lines similar to those of the Royal Commission after the 1914-18 war. Consequently we may expect some such action to be taken where Section 29 does not quite fit the case.

Despite great difficulties, order will reign in our patent matters, owing to experience acquired from the previous world war. Neutral countries may be expected to come pretty well out of the morass too, because their hardships are not so great as ours.

Germany has dealt with her patent affairs much on the same lines as we have, it would seem. Last time there was a set-off between that country and the United Kingdom of Government funds accumulated from patent, etc., sources. We came off slightly better. There was efficient administration in the German Patent Office. In patent and allied matters our adversaries did not show vindictiveness.

Very likely the orderly German mind will manage to keep control of the patent system on this occasion also. They are using enemy patents to advance their own war measures. At least so their war provisions relating to industrial property would seem to indicate. They have not, according to these orders, confiscated patents. They have every incentive of caution not to be revengeful this time.

When we come to Occupied Europe, things do not seem so clear. Nazidom has laid a heavy hand on industry and its workers. Enforced service, conscription, victimisation and simple "liquidation" have been the order of the day, amongst technical men and workers in the invaded countries at least; conversations with refugees, and information as to transfer of patent businesses into German hands from evident nationals of defeated countries, for example, make that clear enough.

An organised effort to destroy the industrial life of those countries, except in so far as they have been marked out for helotry, is scarcely likely to have left patents alone. A moratorium, and a pretty long one at that, would appear necessary to restore justice and order into such a state of affairs.

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## A New Aid to Aircraft Manufacturers

A RATHER ingenious machine has been developed and produced which folds and bends structural sections in one operation. It is known as the Fairey "Benfold." Basically it is a machine which produces curved drawn sections and structural units so produced may be used in main component assemblies without further manipulation. It does in one operation work formerly carried out on the draw-bench to make a straight section, and the hand or form pressing to obtain the required profile. The profile formed with this machine may be constant or of varying radius. Full particulars are contained in a booklet, which may be obtained from the Fairey Aviation Co., Ltd., Hayes, Middlesex.

# Cleaning and Descaling Steel by Electrolytic Pickling in Molten Caustic Soda

By N. L. Evans, B.Sc., A.I.C.

*(Research Department, I.C.I. (Alkali), Ltd.)*

*Many advantages are claimed for the process of cleaning and descaling steel by electrolytic treatment in molten caustic soda. This investigation, reported by the author,* is concerned mainly with finding the optimum conditions of time, temperature and current density, and with the occurrence and prevention of brown stains on the work. Certain electrical conditions in the plant have been investigated, and their bearing on plant design is discussed.*

IN 1936, a British patent† was granted for a process for cleaning and descaling metal by electrolytic action in a bath of molten caustic soda. The specification mentions other chemicals for the bath, such as mixtures of sodium and potassium hydroxides, sodium nitrite and calcium chloride, but so far as the author is aware, caustic soda has invariably been used when the process has been applied in Great Britain. Suitable operating conditions are said to be a temperature of 850° F., a current density of 100 amp. per sq. ft., and an immersion time of 10–15 secs. The metal to be cleaned is made the cathode, the anodes being of nickel or iron. The consumption of caustic soda is said to be 15 lb. per ton in the case of wire.

The process was first developed as a method of cleaning steel wire prior to electro-galvanising, and was applied by the Bethlem Steel Corporation, the combined processes of cleaning and zinc-plating being known as "bethanising." This combined process has been extensively used in Great Britain for the production of galvanised steel wire. More recently, however, experiments have been carried out on a fairly large scale on the descaling of steel sheet by the caustic-soda process, not as a preliminary to galvanising, but as a final treatment which confers a mild degree of resistance to rusting for an appreciable period, in contrast to the rapid rusting which follows pickling in acid.

The main object of the present investigation was to find the most favourable conditions of temperature, time and current density for carrying out the process. In the course of the investigation a considerable amount of information has been collected on such subjects as the design of plant, safety precautions, the descaling of certain alloy steels, and such-like, which is recorded for users and potential users of the process.

* Iron and Steel Institute paper. Advance copy, April, 1944.
† No. 442,859.

TABLE I.
TYPES OF ORDINARY MILD STEELS USED.

| Steel No. | Description. | Analysis. C, % | Si, % | S, % | Mn, % | P, % | Remarks. |
|---|---|---|---|---|---|---|---|
| 1 | Rusty ..... | 0·088 | Trace | 0·047 | 0·36 | 0·045 | |
| 2 | Uniform blue scale.. | 0·03 | 0·083 | 0·045 | 0·28 | 0·020 | Trace of nickel present. |
| 3 | Blue scaled borders. | 0·062 | Trace | 0·049 | 0·20 | 0·027 | Only outer borders of sheet used. |
| 4 | Blue scaled borders. | 0·070 | Trace | 0·082 | 0·38 | 0·054 | Only outer borders of sheet used. |
| 5 | Blue scaled borders. | 0·040 | Trace | 0·034 | 0·27 | 0·066 | Only outer borders of sheet used. |
| 6 | Blue scaled borders. | 0·052 | Trace | 0·030 | 0·27 | 0·013 | Only outer borders of sheet used. |
| 7 | Uniform blue scale . | 0·068 | Trace | 0·021 | 0·31 | 0·025 | |
| 8 | Straw temper selected | 0·059 | Trace | 0·049 | 0·22 | 0·018 | Only temper-coloured area of sheet used. |
| 9 | Blue temper selected | 0·059 | Trace | 0·049 | 0·22 | 0·018 | Only temper-coloured area of sheet used. |
| 10 | Killed or semi-killed | 0·074 | 0·042 | 0·034 | 0·031 | 0·022 | |
| 11 | Straw temper selected | 0·054 | Trace | 0·053 | 0·030 | 0·013 | Brown stain investigation only; not in comparative tests. |

TABLE II.
TYPES OF STAINLESS AND SILICON STEELS USED IN EXPERIMENTS.
Analyses of Nos. 12 to 18 made by the manufacturers.

| Steel No. | Description.° | Analysis. C, % | Si, % | S, % | Mn, % | P, % | Cr, % | Ni, % | Ti, % |
|---|---|---|---|---|---|---|---|---|---|
| 12 | 880 stainless steel.... | 0·11 | 0·43 | — | — | — | 16·5 | 1·62 | — |
| 13 | Low-carbon 12–14% chromium stainless iron. | 0·09 | 0·20 | — | — | — | 12·6 | 0·22 | — |
| 14 | 20% chromium stainless iron. | 0·05 | 0·40 | — | — | — | 20·4 | 0·32 | — |
| 15 | 18/8 austenitic stainless steel (welding quality). | 0·12 | 0·56 | — | — | — | 18·0 | 9·2 | 0·85 |
| 16 | 16/11 austenitic stainless steel (welding quality). | 0·15 | 1·27 | — | — | — | 15·4 | 11·5 | 1·05 |
| 17 | 18/8 austenitic stainless steel. | 0·14 | 0·30 | — | — | — | 18·8 | 8·6 | — |
| 18 | Cutlery-type 12–14% chromium stainless steel. | 0·30 | — | — | — | — | 12–14 | — | — |
| 19 | 4% silicon steel, C.A. and N. | 0·024 | 3·96 | 0·016 | 0·09 | 0·032 | 0·08% aluminium | | |
| 20 | 0·25% silicon steel, C.A. and N. | 0·021 | 0·25 | 0·039 | 0·34 | 0·044 | Trace aluminium | | |
| 21 | 4% silicon steel, C.A. | Analyses as for corresponding close-annealed and normalised material. | | | | | | | |
| 22 | 0·25% silicon steel, C.A. | | | | | | | | |
| 23 | 4% silicon steel, hard rolled. | | | | | | | | |
| 24 | 0·25% silicon steel, hard-rolled. | | | | | | | | |

° C.A. and N. = close-annealed and normalised. C.A. = close-annealed.

TABLE V.—RESULTS OF DESCALING EXPERIMENTS: MILD STEELS, STAINLESS AND SILICON STEELS.

Except for Nos. 13, 15 and 16, for which sufficient metal for 8 specimens only was available, 18 test-pieces were prepared from each material. The specimens were numbered from 1 to 18, and the individual results are entered in the Table in accordance with the "key to specimen numbers" at the foot.

| Steel No. | Description. | | Time Min. | Current Density and Temperature. | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | 100 amp. per sq. ft. at— | | | 200 amp. per sq. ft. at— | | |
| | Untreated Surface Finish. | Appearance after Treatment. | | 350° C. | 425° C. | 500° C. | 350° C. | 425° C. | 500° C. |
| 1 | Rusty sheet. | | ½ | X | X | A | ε | A | A |
| | | | 1 | A | ε | S | A | A | A |
| | | | 2 | A | A | A | A | A | A |
| 2 | Smooth blue scale, moderately thick. | | ½ | X | X | X | S | sε | A |
| | | | 1 | X | X | s | S | A | A |
| | | | 2 | ε | A | ε | s | A | A |
| 3 | Dull blue scale, moderately thick. | s probably due to short-circuit. | ½ | ε | S | A | s | s | S |
| | | | 1 | A | A | A | A | A | A |
| | | | 2 | A | A | s | A | A | A |
| 4 | Dull blue scale, moderately thick. | | ½ | X | X | X | X | sε | ε |
| | | | 1 | X | X | ε | ε | A | S |
| | | | 2 | X | s | S | s | A | S |
| 5 | Dull blue scale, moderately thick. | | ½ | X | X | X | X | ε | s |
| | | | 1 | sX | X | A | X | A | s |
| | | | 2 | X | s | S | X | A | S |
| 6 | Dull blue scale, moderately thick. | Stain mainly on rough side. | ½ | ε | X | ε | sε | ε | s |
| | | | 1 | S | ε | s | sε | s | s |
| | | | 2 | A | A | s | s | s | A |
| 7 | Smooth blue scale, moderately thick. | Slight stain only, except specimen 18. | ½ | X | s | A | X | A | s |
| | | | 1 | X | A | s | A | A | A |
| | | | 2 | X | A | A | A | A | S |
| 8 | Smooth straw/blue temper colour. | Specimens 10–12 difficult to distinguish stain. Specimen 17 slight stain only. | ½ | X | X | z | X | S | z |
| | | | 1 | X | A | S | X | A | S |
| | | | 2 | X | S | A | S | S | s |
| 9 | Smooth blue temper colour. | Specimen 16 slight stain only. | ½ | A | S | s | A | A | s |
| | | | 1 | S | A | A | A | A | A |
| | | | 2 | S | A | s | A | A | S |
| 10 | Killed steel. Thick blue scale, streaked. Streaks remained visible after descaling. | | ½ | X | Sε | S | Sε | S | s |
| | | | 1 | sε | s | s | S | S | s |
| | | | 2 | sε | SX | s | S | S | s |
| 12 | 880 stainless steel. Smooth blue, moderately thick scale. | Specimen 18 very slight stain only. | 1 | — | X | X | — | sε | sε |
| | | | 2 | — | A | s | — | A | S |
| | | | 4 | — | — | — | — | — | S |
| 13 | Low-carbon, 12–14% chromium stainless iron. Smooth purple, moderately thick scale. | | 1 | — | X | X | — | X | S |
| | | | 2 | — | sε | s | — | X | A |
| 14 | 20% chromium stainless iron. Smooth blue, moderately thick scale. | All except specimens 1 and 2 nearly completely descaled. Specimen 18 very bright. | 1 | — | X | X | — | X | X |
| | | | 2 | — | X | X | — | X | X |
| | | | 4 | — | — | — | — | — | A |
| 15 | 18/8 austenitic stainless steel (welding quality). | | 1 | — | ε | ε | — | ε | A |
| | | | 2 | — | ε | ε | — | ε | A |
| 16 | 16/11 austenitic stainless steel (welding quality). Dull blue and rusty scale. | Specimen 17 slight stain only. | 1 | — | S | Sε | — | X | s |
| | | | 2 | — | ε | X | — | Sε | s |
| 17 | 18/8 austenitic stainless steel. Patchy scale and rust spots. | | 1 | — | X | X | — | X | X |
| | | | 2 | — | X | X | — | X | X |
| | | | 4 | — | — | — | — | — | ε |
| 18 | Cutlery-type 12–14% chromium stainless steel. Thick scale and rust. | Specimen 17 nearly completely descaled. | 1 | — | X | X | — | X | X |
| | | | 2 | — | X | X | — | X | X |
| | | | 4 | — | — | — | — | — | A |
| 19 | 4% silicon steel, close-annealed and normalised. Thick scale both sides. | Specimen 6 stain due to contact. Specimens 8, 9, 17 and 18 very slight stains. | ½ | X | X | S | s | s | S |
| | | | 1 | X | S | S | s | s | S |
| | | | 2 | SX | s | S | A | A | S |
| 20 | 0·25% silicon steel, close-annealed and normalised. Moderately thick scale both sides. | Specimen 9 stain by rough surface. Specimen 13 stain due to contact. | ½ | S | s | s | sε | s | s |
| | | | 1 | sε | s | A | sε | A | S |
| | | | 2 | A | A | s | A | ε | A |
| 21 | 4% silicon steel, close-annealed. Thick scale one side; patchy on reverse. | | ½ | S | s | s | s | s | S |
| | | | 1 | S | s | s | s | A | S |
| | | | 2 | S | A | A | A | A | S |
| 22 | 0·25% silicon steel, close-annealed. Thick patchy scale one side; very little scale on reverse. | Specimens 17 and 18 stains due to contact. | ½ | X | ε | s | ε | A | s |
| | | | 1 | ε | ε | s | ε | s | s |
| | | | 2 | X | A | A | A | s | s |
| 23 | 4% silicon steel, hard rolled. Thick scale one side; practically none on reverse. | Stain only slight in all cases. | ½ | A | s | S | s | s | s |
| | | | 1 | s | s | S | s | s | s |
| | | | 2 | s | s | s | s | S | A |
| 24 | 0·25% silicon steel, hard rolled. Moderately thick scale both sides. | Specimen 6 very good silvery surface one side. Specimen 9 very slight stain only. Specimens 14, 15 and 17 stains due to contact. | ½ | X | sε | sε | sX | sε | sε |
| | | | 1 | X | sε | sε | ε | sε | s |
| | | | 2 | X | ε | sε | sε | sε | s |

KEY TO RESULTS.

A. Satisfactory descaling without brown stain.
ε. Satisfactory descaling on one side only; without brown stain.
X. Unsatisfactory descaling on both sides.
z. Unreliable results; probably short-circuit.
S. Large areas brown stain, otherwise satisfactory.
s. Small areas brown stain, otherwise satisfactory.

Key to Specimen Numbers.

| | | | | | |
|---|---|---|---|---|---|
| 1 | 4 | 7 | 10 | 13 | 16 |
| 2 | 5 | 8 | 11 | 14 | 17 |
| 3 | 6 | 9 | 12 | 15 | 18 |

### Scheme of Work

A scheme was laid down for caustic soda pickling in an experimental pickling cell, which is described, providing all combinations of three working temperatures, 350°, 425°, and 500° C. with three time periods, ½, 1 and 2 mins., and two values of current density, 100 and 200 amp. per sq. ft. Thus 18 different results were obtained for each of the mild steels in Table I, and for each of the silicon steels in Table II. Owing to restricted supplies of the stainless steels in Table II, only eight tests per sample were carried out, covering the combinations of two temperatures, 425° and 500° C., with two time values, 1 and 2 mins., and two current values, 100 and 200 amp. per sq. ft. The results of these experiments are shown in Table III.

The main point at issue in each test is the efficacy of scale removal. Other features are the incidence of brown stain, and in special cases the effects of fissures and surface flaws. While there are anomalies in the results, due sometimes to initial differences in the scale on individual samples and to defects in the cell, a useful picture of the comparative effects of temperature, current density and time is presented.

### Efficiency of Descaling

In general, as Table III shows, a slightly superior result for an equal expenditure of energy is obtained by employing the higher current density over a shorter period of time. All the ordinary steels of Table I may be satisfactorily stripped of scale. Steels Nos. 3–6 are moderately scaled only along the outer sides of the sheets, and Nos. 8 and 9 are temper-coloured only along a central band. In all cases these oxidised areas were selected for the experiments. Prolonged treatment produces a bright silvery finish.

Ordinarily heavily rusted strip is particularly easy to treat, complete stripping being obtained under all but the minimum operating conditions. The moderately thick dull-blue scales and the temper colours ranging from a straw tint to purple are more resistant, but in all cases yield to the medium or higher values of treatment.

The stainless and silicon steels are in many cases more difficult to treat than the mild steels, though, with the exception of No. 17, all may be satisfactorily stripped at the higher treatment values. Steels Nos. 14, 18 and 24 called for the maximum treatment to obtain good results, while the others yielded to the lower or medium values.

### Removal of Sponge Iron after Descaling

The black film of sponge iron which remains on the surface of the sheet after treatment is easily removed on quenching in cold water. Much of it is immediately dispersed in the water and a light brushing afterwards quickly removes the remainder. An immersion in boiling water completes the operation.

In certain cases, such as sheet heavily rusted on one side or the steels of the types of Nos. 4, 5 and 6, one side is often found to be considerably rougher than the other, and very vigorous brushing is required to remove the sponge iron embedded in the pitted surface. After brushing, drying off should be expedited in every way possible, such as by hot-air circulation. Delay in the removal of the last traces of water frequently gives rise to staining.

### Causes of Brown Stain

A statistical examination of the results of experiments was carried out in order to discover whether any of the factors—time, temperature or current density—might be associated with the occurrence of brown stain. The results, as shown in Table III, were variously arranged into groups of particular time, temperature or current characteristics. Graphs were prepared showing the trend of frequency with which brown stain was observed under separately changing conditions. From this analysis temperature emerged as the major causative factor in producing brown stain. Above 400° C. there are increasing tendencies towards its appearance.

The investigation established that copper conducting bars with nickel cathode holders and excessive currents and times are not material factors in the production of brown stain, but that control of temperature, maintenance of a clear electrolyte, good insulation, expeditious removal of the work from the cell and proper control of the quenching are the important factors in preventing stain.

A further brief treatment lasting only a few seconds in the caustic soda cell provides a certain means of eliminating all types of brown stain.

### Summary of Results

The experiments carried out show clearly that the results of the treatment are better as the time, temperature and current density are increased. It is recommended that 425° C. and 200 amp. per sq. ft. should be regarded as minimum conditions, and that the time should be adjusted according to the type of scale to be removed. It will probably be of the order of 1 min., except in the case of certain highly alloyed steels, such as stainless, which may require a higher current density or a time as long as 4 mins.

In the descaling of wire, much higher current densities than 200 amp. per sq. ft. are used. Experience may show that such conditions are advantageous for other applications.

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## Iron and Steel Research

THE first meeting of the British Iron and Steel Research Association was held on April 19, with Sir James Lithgow, Bt., M.C., in the chair.

Sir James Lithgow was elected president of the new Association, and Dr. Andrew McCance, F.R.S., was elected chairman; and immediate steps are being taken to appoint a director of research and a principal administrative officer of the Association.

In the meantime, pending completion of the organisation of the staff, the Iron and Steel Industrial Research Council will continue to be responsible for the large volume of research which is at present in progress, and the transfer of responsibility for the direction of this will not be made until the new organisation is complete with director and headquarters staff. It is recognised that, particularly under present conditions, the requisite steps will take a month or two to complete. With the liberal financial provision which has been made by the British Iron and Steel Federation for an expenditure up to £250,000 per annum, a considerable expansion in present research activities is expected immediately the requisite personnel becomes available.

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At the annual general meeting of the Maudsley Society, held at the Institution of Mechanical Engineers, Colonel Philip Johnson, D.S.O., M.I.Mech.E., was installed as President for the coming year.

# The Institute of British Foundrymen

## Annual General Meeting held in Manchester

CONSIDERABLE enthusiasm was displayed at this, the 41st annual general meeting of the above Institute, held in Manchester on June 9 and 10. The afternoon of the first day was devoted to meetings of the Council and various Committees, while during the evening two papers were presented to which reference will be made later in this report.

The business meeting, held the following morning before a good attendance of members, opened with the President, Mr. D. Sharpe, in the chair. After the minutes of the previous annual meeting had been taken as read, the president presented the annual report of the Council and commented on one or two of the high spots. Despite war conditions, it is noteworthy that membership has increased very materially; in this respect, particular mention was made of the London Branch which had put up an unbroken record. The work this Branch had been able to do was very creditable. Another point especially stressed was the work of the Education Committee, and tribute was paid to the work of the chairman of that Committee (Mr. S. H. Russell, past president).

This latter Committee has been most active during the year, and its findings on some matters connected with apprentice training and education have been published in Special Report No. 4. The Committee has also given evidence before a Committee on the Training of Metallurgists appointed by the Department of Scientific and Industrial Research. Close touch has been maintained with the authorities of the University of Sheffield in connection with the Degree Course in Founding and with the City and Guilds of London Institute Advisory Committee on examinations in foundry practice and science and in pattern-making.

### Report of Technical Committee

The twelfth annual report of the Technical Committee was presented by Mr. J. W. Gardom, the convener, who commented on the reorganisation of the Committee, the purpose of which was to enable it to do more work and to bring more people into it. The report indicates that this Committee, too, has been very active during the year. In view of his nomination as president of the Institute, Mr. Gardom relinquished the convenership of the Technical Committee, a post which he has held for many years. In proposing the adoption of the report, Mr. Gardom wished his successor, Mr. P. A. Russell, every success. Mr. Russell, in seconding the adoption of the report, said he would do his best to carry on the work of the Technical Committee in the tradition established by Mr. Gardom.

### Oliver Stubbs Gold Medal

The president announced the award of the above for 1944 to Mr. W. Y. Buchanan, a member of the Scottish Branch since 1932. Mr. Buchanan has delivered more than a dozen papers to the Institute and its branches, and many of them have involved original research work. His main studies have been in connection with sand-testing and properties, and, more recently, in connection with the effect of gases in cast iron. Apart from his contributions to the technical activities of the Institute, he has been a most active member of the Scottish Branch, on whose Council he has served for a number of years, and has recently been elected a member of the Council of the Institute. Mr. Buchanan was presented with a certificate in token of the Medal, which could not be made in war-time, and suitably responded.

### E. J. Fox Gold Medal

The president announced the award of this Medal to Mr. FitzHerbert Wright, and, as Mr. E. J. Fox, the donor of the Medal, was present, he was asked to make the presentation. In making the award, Mr. Fox said that Mr. Wright was a director of Butterley Ironworks, Ltd., and a director of the London and North Eastern Railway Co. He was a vice-president of the British Cast Iron Research Association and a member of the Departmental Committee appointed by the President of the Board of Education to report on future collaboration between universities and technical colleges on higher technological education in relation to the needs of industry. Mr. Wright is also chairman of the Council of Iron-foundry Associations, and it was particularly in recognition of his outstanding contribution to the progress of the foundry industry through his efforts in forming and organising the Council that the Institute had honoured him with the award. The merging of the interests of affiliated societies and associations in the foundry industry, Mr. Fox said, was a most important work.

In accepting the award, Mr. Wright said that apparently the Medal could be awarded to those who were endeavouring to make a homogeneous man as well as to those who were trying to make homogeneous castings; and perhaps the attempts to develop the homogeneous man were the more difficult. It was due to the wonderful help he had received during the last three or four years from his many friends, including those in the foundry industry, that he had been able to do the work which had resulted in the award of the medal.

### The British Foundry Medal

The first award of this Medal (given annually from a fund of £500 provided by Mr. Barrington Hooper, C.B.E., and Industrial Newspapers, Ltd., as an award to the author of the best paper presented to the Institute during the year) was made to Mr. J. W. Gardom; a cash award connected with the presentation was made to Mr. E. Longden for his contribution. In making the presentation, Mr. Hooper said it was an honour that the first award should be made to one who had done so much by his untiring efforts, not only for the Institute, and especially in connection with the Technical Committee, but in other directions. In response, Mr. Gardom said the paper in respect of which the award was made dealt with the mechanism applied to the production of manganese steel track links. The interesting point about the method adopted was that scientists had said the work could not be done in the way proposed. But in fact it was done, and in a very satisfactory manner. Further, after producing the links, the foundry

was reorganised within seven days for the production of agricultural plant.

The cash award to Mr. Longden was for his paper on "Fluid Pressure in the Foundry." Mr. Longden was unable to be present, but tribute was paid to him, not only in respect of one particular paper, but for his efforts to forward the interests of the Institute and the industry.

### Diplomas

The Council awarded the Institute's Diploma to Mr. I. Ross, for a paper on "Magnesium Foundry Technique"; to Mr. R. C. Tucker for a paper on "Cupola Operation and Control"; to Mr. A. Wood for a paper on "A Small Moulding Unit"; to Mr. M. R. Hinchcliffe for a paper on "An Outline of Gravity Die-casting"; and to Mr. J. Blakison for a paper on "Mechanical Aids in Core Production."

### Original Members

An interesting diversion from the normal business of the meeting was the presentation to the Institute of the photographs of twelve original members who had been "on active service" with the Institute for 40 years. Mr. J. S. G. Primrose conceived the idea and made the presentation, and the photographs, which included Mr. F. J. Cook, Mr. J. T. Goodwin, Mr. C. E. Williams, Mr. J. J. McClelland, Mr. R. L. Rankin, Mr. J. Galt, Mr. J. N. Chadwick, Mr. T. W. Markland, Mr. W. H. Meadowcroft, Mr. W. B. Parker, Mr. K. M. Burder, and Mr. D. A. Aston, were handed to the Secretary for safe keeping.

### Election of Officers

The President proposed and Mr. C. H. Kain seconded the election of Mr. J. W. Gardom as president for the ensuing year. In acknowledging his appreciation of the honour conferred upon him, Mr. Gardom took the opportunity to propose the thanks of the Institute to Mr. Sharpe for his able conduct of the affairs of the Institute during the past year.

Further elections included Mr. D. M. Wood, senior vice-president, and Dr. T. Swinden, junior vice-president. The members of Council elected for the two years ending 1946 were Mr. H. Bunting, Dr. A. B. Everest, Mr. E. J. L. Howard, Mr. A. Phillips, and Mr. R. B. Templeton.

### Presidential Address

After his introductory remarks Mr. Gardom said the first man to work metal must have been a practical man, and his skill through the ages was passed on, mainly by example, with constant improvement, until the first casting was produced. So was born our present-day artisan. Then, as now, our artisan had not only to be skilled in manipulation, but also to have a basic understanding of the materials used. He denoted this worker by a capital "A."

As skill and knowledge improved it was natural that more thought must be given to the processes of production and improvement of the product. More and more time was given to studying "why," so a new type was created which pondered, reflected, reasoned, and drew inferences, and so was born the academic man, whom he denoted by a capital "A" and small "m."

As this practice of thinking increased, the distance between the two classes of workers grew wider and wider until an almost impenetrable wall was erected between them. This he demonstrated with the letter "I." The rate of progress was now delayed until the wall had been scaled, but as both had started at the beginning, it was natural that pioneers would be found to carry problems from left to right and the solution right to left, and so was born the technical man, denoted by the letter "T," and from the arrangement A T Am the technical man's requirements and training can be visualised.

It can be seen that to enter this sphere the academic man can come down from the University and the practical man can come up from the foundry floor, providing each has the capacity to appreciate and understand the other's work. For this is truly the field of the technical man, to understand the problems, to appreciate the research results, and to apply and demonstrate them for the betterment of all. The wide knowledge and experience of both the practical and theoretical make him realise that we have only scratched the surface of knowledge and accomplishment. The technical man is always ready to discuss and explain the "how" and "why" of his work, so that all facts can be verified and all experiments reproduced. He has developed, to a very high degree that greatest of all assets, the power to look and see, or what is called vision.

In order that more and more and even better technical men may become available to keep pace with modern demands, Mr. Gardom stressed the need for a definite qualification for which promising apprentices could be prepared by study. He would like to see established a Technical Diploma which would show that the holder not only had knowledge of foundry subjects, but also that he had satisfactorily filled a works position for two or three years. Thus, the degree man would be required to fulfil the examiners' requirements in practical application, while the practical man would have to demonstrate his knowledge of the theory. He suggested that the diploma would allow men who develop their full powers after leaving school or after works' experience to obtain recognised qualifications of their ability. He felt sure that this work could be undertaken by the newly constituted Technical Council.

## TECHNICAL SESSIONS

A considerable number of papers were presented for a meeting of short duration, but by dividing them into convenient sections their presentation was simplified. Two sessions were allocated to the presentation and discussion of these papers; the first of these was held at 8 p.m. on June 9, at which two papers were presented: one by the Mechanical Development Sub-Committee of the Technical Committee and the second on Sand-slinger moulding practice. The second session was held in the afternoon of the following day, and comprised three sections. Four papers were presented in Section A, dealing with steel mixes and inoculants in grey cast iron; the development and production of inoculated cast iron; war-time developments in Whiteheart malleable; and the speeds of rotation in the centrifugal process. Section B comprised four papers and deal with the control of composition and heat-treatment in 0·25% C, 1·5% Mn steel castings; relationship of Brinell hardness and yield stress in certain cast steels; modification by heat-treatment of cast structures and properties; and the Melting Furnaces Sub-Committee presented its first report on basic lined cupolas. Two papers were presented in Section C, one, the exchange paper of the American Foundrymen's Association, dealt with war-time calls on women to make aluminium air-cooled cylinder heads; while the other was concerned with the mechanised production of gravity die-castings. Brief reference to these papers will be of interest.

## MECHANICAL HANDLING IN FOUNDRIES

THIS is a report by the Mechanical Development Sub-Committee of the Technical Committee, which reviews the more important mechanical handling methods and devices employed in foundries for the handling of materials from the time of their receipt to the dispatch of the finished castings. The Sub-Committee is concerned only with general principles of each method or device described, and in no case has it recommended any particular proprietary article or piece of plant. Furthermore, the report is confined to the handling of foundry materials and products as distinct from processing operations.

The report deals with all the principal alternative methods for each stage of material handling, and the economic and technical advantages and limitations to the employment of each method are indicated. The Sub-Committee appreciate that almost infinite variations may be made to suit the individual requirements of any particular foundry, but it is impossible to discuss all these at any length. Some of the more frequently recurring variations are, however, mentioned. The report is divided into ten sections, each representing one of the major stages in the handling of materials in the production of castings. These comprise the stock yard; the stock yard to melting furnaces; molten metal; moulding sand; moulds; core sand and cores; heat-treatment; fettling shop; inspection; and storage and dispatch.

Facilities for the mechanical handling of the raw materials received into the stock yard by rail, road and water are discussed and recommendations made. These are concerned with the discharging of metal; lump coal, coke, sand and limestone; and with refractory brick and ganister. Particular mention is made of storage bins, and it is recommended that two sets of storage bins be provided, one set to be used for main storage and the other for working stock. The main storage bins, which need not be immediately adjacent to distributive points, should contain up to, say, two months' supply; the working stock bins, on the other hand, should be situated close to the foundry for immediate day-to-day requirements. It is unnecessary to deliver incoming materials to the storage bins; they should, as far as is possible, be delivered to the working stock bins. The control of materials is facilitated by the adoption of this method.

From the stock yard to the melting furnaces, handling methods are discussed for the various types of furnaces employed, including cupola; converter; open-hearth; electric; rotary; and air furnaces. Attention is directed to charging methods, and it is stated that for cupolas having a capacity in excess of 5 tons per hour it is an advantage to employ mechanical skip charging for charges up to 10 to 12 cwt., and the drop-bottom bucket method for charges greater than this. For cupolas which have to supply continuous casting plants mechanical skip charging is recommended, but care must be taken in the preparation of small charges. Where skip charging is employed the charging door of the cupola shou'd be at east 1 ft. 6 in. above the normal level, and should be fitted with a hinged baffle plate to prevent the charges wearing the lining opposite the door and also to give a better distribution. An auxiliary door for inspection should be provided at right angles to the charging door.

The advantages and disadvastages of having the stock yard at cupola stage level, when conditions permit, are discussed, and attention is given to facilities for weighing cupola charges. Methods employed for the various types of furnaces are discussed separately.

In the case of molten metal, which may be tapped continuously or in batches, the method of transporting metal to the moulds depends upon the quantity to be handled and the distance to be travelled. For small quantities and short distances the metal may be carried away in hand shanks, but for medium quantities the metal may be run into geared tilting ladles on bogies. Another method of handling medium quantities of metal is by hand-tilting or geared tilting ladles on trolleys or travelling pulley blocks running on rolled steel joists or built-up steel sections. Medium to large quantities of molten metal are usually handled by overhead travelling cranes direct to the pouring points when the tapping spouts and pouring stations are in the same bay. When metal has to be transferred to other bays, the method usually adopted is by bogies, or ladles may be transported on power-driven trucks. Monotracks or rails should be continued past the furnaces to permit adequate storage space. Special types of ladles may be necessary to conserve the heat of the metal where it has to be carried some distance.

Considerable attention is naturally given to the handling of moulding sand. Methods discussed include those suitable for hand and machine moulding. In fully mechanised sand systems the conveyers and elevators used generally fall into five distinct types—bucket elevators; tilting-bucket conveyers; flat and troughed belt conveyers; scraper or push-plate conveyers; and apron-plate conveyers. These are discussed separately.

The handling of moulding boxes presents very real problems, and should be given serious consideration if the foundry is to produce the output of castings of which it should be capable. In foundries employing moulding machines and mechanised sand-handling systems the following types of conveyers are available for this purpose: Roller track; overhead chain conveyer; plate type floor conveyer; slat conveyer; and walking bear conveyer. Each of these conveyers may be used separately or in combination to achieve the desired object.

Core sand may be delivered and discharged into storage bins in the same manner as moulding sand. It is necessary to dry core sand before use in order to maintain a uniform moisture content to effect standardisation in mixing. For this purpose either a stationary or rotary drier may be used according to the condition of the sand. After drying the sand is conveyed to storage, preferably over mixers, much in the same way as moulding sand. For conveying the mixed core sand, the overhead chain conveyer and tilting buckets are satisfactory. Cores are transferred to baking ovens on flat trays and may be conveyed by elevating platform trucks, roller track, steel mesh or steel band conveyer, and overhead chain conveyer.

The handling of castings in the fettling shop depends much on the layout of the foundry and the character of the castings with regard to weight and bulk. In this report the facilities for jobbing foundries and mechanised foundries are discussed separately.

Many of the technical considerations which have to be taken into account in the selection of mould, core and sand conveyers do not apply to the conveying of castings in the inspection department. Economy in

handling and accessibility to the castings to be inspected are the main objects to be aimed at, but to achieve these objects successfully several factors are involved, which include the general layout of the plant; amount of inspection necessary; maximum and minimum weights of castings; quantity of castings to be handled; and it is necessary to ensure that no castings fail to be inspected. For this purpose various types of conveying appliances are discussed.

In dealing with the handling of the finished castings distinction is drawn between the temporary storage of castings which are awaiting dispatch and storage of stocks or warehousing.

This report includes an Appendix giving data on the capacity, speeds, etc., of various handling units, although it is appreciated that wide variation of the figures given will be found in practice, they are typical of foundry applications.

## STEEL MIXES AND INOCULANTS IN GREY CAST IRON

By W. BARNES and C. W. HICKS.

MUCH has been written about the inoculants and alloy additions in modern high-duty cast iron, and very little about effects of the various amounts of steel in the mix, but there is no doubt that the steel content of the charge is the greatest basic factor in the results obtained. There has been, and still is, too much misconception and doubt about the cupola melting of steel, and because of this many foundries are operating under high metal costs.

As production conditions are the acid test of any process, the authors describe a series of experiments carried out on a cupola which is in daily use for normal production. The chief purpose of the investigation was to measure the effect on physical properties of increasing percentages of steel with or without a measured amount of various inoculants. The second purpose was to measure the effect of a fixed percentage of steel and varying amounts of inoculants. The third purpose was to ascertain the effect of increasing percentage of steel on the reaction of the resultant iron to low-temperature treatment, and to oil quenching. The materials used as inoculants were calcium silicide, ferro-silicon, aluminium, a mixture of aluminium and ferro-silicon, and nickel shot.

In dealing with the melting practice employed, the authors describe the cupola, its standard preparation before charging, the formation of the bed, etc. The compositions of the raw materials and of the charges used are shown in Tables I and II.

To obtain as consistent a melting condition as possible, the metal charges to be used for tests were placed on the cupola in the same sequence during each melt. The third to the twelfth charges, or, in other words, ten consecutive 5-cwt. charges were made up with the percentage of steel to be examined, and the metal tap corresponding to the two centre charges, the seventh and eighth, was used for casting the test-bars.

A hand ladle to hold 10 lb. of iron was placed under the spout 10 secs. after the tap-hole was opened, and immediately after the sample was obtained the inoculant was fed on to the metal stream on its way to the main ladle. To effect this, a measured amount of inoculant was placed in a hopper fixed over the tapping spout, and immediately after the taking of the untreated sample the hopper slide was opened and the speed of addition regulated to distribute the inoculant throughout the tap. When the 10-cwt. ladle was full, a hand-ladle was used again to cast the test-bars, and the main ladle used for ordinary production.

A standard wedge test-bar was used as a metal control, and the chill depths were fixed at values of 6 and 4 for the untreated and treated iron respectively. These standards were observed for all the series of tests on increasing percentages of steel with a consistent addition of the various inoculants, and any metal with other than these chill values was discarded for the 10, 20, 30, 40, 50 and 60% steel mixes. The 0% steel irons had wedge values of 4 and 3, and the 70% steel mixes had values of 7 and 5. In the series of tests on standard percentages of steel with increasing amounts of inoculants, the chill depths naturally decreased as the inoculant increased.

TABLE I.

COMPOSITION OF RAW MATERIALS.

| Metal Grade. | Si. | S. | P. | Mn. |
|---|---|---|---|---|
| | % | % | % | % |
| Steel | 0·20 | 0·05 | 0·05 | 0·60 |
| Pig-iron No. 1 | 3·10 | 0·04 | 0·36 | 1·1 |
| Pig-iron No. 2 | 4·50 | 0·06 | 0·37 | 1·5 |
| Pig-iron No. 3 | 0·18 | 0·014 | 0·032 | 0·35 |
| C.I. scrap No. 1 | 1·70 | 0·06 | 0·25 | 0·80 |
| C.I. scrap No. 2 | 2·50 | 0·09 | 0·35 | 0·75 |
| C.I. scrap No. 3 | 2·00 | 0·07 | 0·30 | 0·70 |
| Ferro-silicon | 14·4 | — | — | — |

TABLE II.

METAL MIXTURES USED.
(Percentages of raw materials.)

| Metal Grade. | % | % | % | % | % | % | % | % |
|---|---|---|---|---|---|---|---|---|
| Steel: | 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 |
| Pig-iron No. 1 | 30 | 30 | 40 | 30 | — | — | — | 10 |
| Pig-iron No. 2 | — | — | — | 10 | 20 | 35 | 20 | 10 |
| Pig-iron No. 3 | 35 | 25 | — | — | — | — | — | — |
| C.I. scrap No. 1 | 35 | 35 | 40 | 30 | — | — | — | — |
| C.I. scrap No. 2 | — | — | — | — | 30 | 15 | 15 | — |
| C.I. scrap No. 3 | — | — | — | — | 10 | — | — | — |
| Ferro-silicon | — | — | — | — | — | — | 5 | 10 |

### Increasing Steel and with Fixed Amount of Inoculant

The first series of tests were to show the effect on tensile strength of increasing the steel content of the charge from 0 to 70% by 10% changes, and of a fixed amount of inoculant with each increase of steel.

*Ferro-Silicon.*—Using an 80% ferro-silicon powder as an inoculant, a steady increase is showu in tensile strength from 14·5 tons with 0% steel to 18·6 tons with 70% steel. With a fixed 60 oz. of inoculant per ton of metal, there is an increase in strength of 0·3 ton to 0·8 ton as the steel content rises.

*Calcium Silicide.*—The series of casts from 0% steel to 70% steel show an increase in tensile strength from 14·3 tons to 18·5 tons per sq. in., and the intermediate figures bear a true relationship. With a fixed addition of 60 oz. of silicide per ton of metal, the strength increases by 0·8 ton to 1·8 tons with increasing steel.

*Nickel.*—An addition of 1·0% nickel by means of nickel "F" shot was adopted for this series, and the tensile values without the alloy addition increased from 14·6 to 19·4 tons per sq. in. With the standard addition of nickel the strength increased 0·7 tons, with 0% steel to 2·1 tons with 70% steel.

*Aluminium/Ferro-Silicon.*—This inoculant has been developed by the authors and consists of seven parts of

80% ferro-silicon and three parts of aluminium swarf, mixed and ground to a B.S.S. 16-mesh sieve. The aluminium and silicon are not alloyed. The results of tests confirm the steady increase in tensile strength with increasing steel. With a fixed addition of 60 oz. of the specified inoculant mixture per ton of metal, there is an increase in strength of 1·0 ton on the 0% steel iron to 3·0 tons on the 70% steel iron.

### Fixed Steel Content with Varying Amounts of Inoculant

As nickel is an alloying element it was omitted from this series. The main series of tests were carried out with 60% steel in the charge.

*Ferro-Silicon.*—The strength of the untreated metal varied from 17·0 to 18·0 tons. After treatment the maximum increase in strength was reached with 40 oz. of addition per ton of metal, after which there was a rapid decrease until, at 120 oz. per ton, the strength fell to 1·3 tons below the strength of the untreated metal.

*Calcium Silicide.*—This inoculant was used on 60% and 30% steel mixes. Tests again show that the strength is greater in the higher steel mix. Here, again, as with ferro-silicon, the optimum effect is reached with the comparatively small addition of 40 oz. per ton of metal, but with increasing additions the strength does not fall below that of the untreated metal.

*Aluminium/Silicon.*—The results of tests confirm that the increase in strength after the addition of the inoculant is greater with the higher steel mix, the maximum increase on 60% steel being 1·5 tons and with 30% steel 1·10 tons. These increases were obtained with 40 oz. of inoculant per ton of metal and there is a fall in strength as the inoculant is increased.

*Aluminium.*—A short series of tests were carried out with additions of aluminium swarf alone. Results show that the optimum increase in tensile strength with a 12-oz. addition per ton of metal is 1·3 ton.

### General Observations

When ferro-silicon is added at the spout there is an endothermic reaction, and the iron becomes more sluggish as the addition increases. With calcium silicide there is a slight exothermic reaction, and increasing additions do not make much difference to the tapping temperature. There is also definite formations of slag particles, which take time to rise and clear. Because of this, it is advisable to hold the ladle for two or three minutes to allow the slag to coagulate.

The addition of aluminium-silicon has approximately the same degree of exothermic action as calcium silicide, but the slag formation is much less. Aluminium alone has a pronounced exothermic action, and the iron appears to be hotter, livelier, and much cleaner than with any other addition.

With all the inoculants tried there appears to be a fairly small optimum amount, after which the graphitising effect of the addition adversely affects the physical properties of the metal in irons which are initially devoid of free cementite. It would appear from this that the greatest effect of such additions up to the optimum amount is in deoxidising the metal, the resultant propagation of nuclei causing a finer graphite formation in the same way that regulated additions of aluminium are used to control the grain formation in steel.

## SANDSLINGER MOULDING PRACTICE

By W. V. BUCHANAN.

THERE are several well-defined methods of consolidating the sand in moulds and cores, such as hand-ramming, jolt ramming, squeeze ramming, blowing, and Sandslinger. It is the latter method to which the author gives special consideration in this paper. With this method the stream of bonded moulding sand is fed into the path of a cup-shaped blade or vane, rotating at a high speed, which picks up the sand in quantities similar to a handful with each revolution, and is thrown vertically into the mould. The velocity of small quantity of sand is such that impact with the sand already in the box actually penetrates and packs on, and so builds up a mass of uniformly rammed sand.

One important advantage claimed for this method of ramming the sand in a mould is the aeration which goes on during the process. This has a beneficial effect on any moulding sand, more particularly if the primary preparation is not what it should be. This, in turn, tends to give much more uniform mould surfaces and a better permeability for equal mould density than is the case in moulds made by other methods.

Experimental data is given showing the relative hardness obtained by jolting or squeezing. They show that a depth of 9 in. cannot be evenly rammed by these methods. To demonstrate the ability of the Sandslinger in this respect, a box was designed to increase the difficulty of ramming. From a number of experiments carried out by ramming this box, using the Sandslinger, the distribution of hardness is shown to be very uniform.

Reference is made to the types of Sandslingers available and to the kinds of moulds for which they are especially suitable. Attention is also directed to the time-saving advantages of this method applying the sand in making moulds, and some examples are given, showing a summary of times by the normal method of production and with the Sandslinger, which demonstrate to the advantage of the latter.

## THE DEVELOPMENT AND PRODUCTION OF INOCULATED CAST IRON

By H. P. HUGHES and W. SPENCELEY.

THIS paper deals with the investigation and experiments which led to regular production of inoculated cast iron developed to replace ordinary cast iron. The shortage of certain desirable materials has presented many problems, not the least being the inadequate supply of suitable base irons. To many the hematite stock in the yard was a regular resort when trouble occurred that was thought to be due to metal, and more often than not the trouble was put right.

In the light of present-day knowledge, hematite could be treated as a naturally inoculated iron due to the graphitising nuclei it contains, an advantage over "synthetic" graphitised irons being its power to retain the graphitising effects over a complete time range, whereas ladle inoculation has a short graphitising period. This may be due to the fact that irons of the "synthetic" type are normally hypoeutectic, and in the hematite range are hypereutectic, so that when once complete solution of the graphite nuclei has taken place, no further graphitising properties are available.

The complete structure of present-day knowledge of

cast iron has been built up to a great extent around graphite, its shape, size and distribution and to a lesser degree in the type of matrix. Having this in view, the author indicates some of these formations found and developed during investigation, so that it may be possible to arrive at a cast iron having the most desirable graphite structure, thus giving the maximum mechanical properties, soundness and good machinability.

Working from the basis that the use of hematite irons showed reduced distortion, and assuming that the beneficial properties were primarily due to their graphitising power, it was decided to try and induce similar conditions by inoculation, so that in this respect it might compare favourably with hematite. Experiments carried out with a view to developing a practical method for the production of a suitable iron to overcome these difficulties are described.

TABLE I.

INCREASE IN MECHANICAL PROPERTIES OF INOCULATED CUPOLA METAL OVER ORDINARY CUPOLA METAL AS DERIVED FROM 15 TESTS ON EACH METAL.

| | | % |
|---|---|---|
| Impact value | Increase | 63 |
| Transverse strength | ,, | 30 |
| Deflection | ,, | 28 |
| Tensile strength | ,, | 23 |
| Brinell hardness | ,, | 2 |

Inoculants other than ferro-silicon were tried, calcium silicide with only a measure of success, the failure being due primarily to the particular practice adopted. Graphite electrodes were also tried, but the inoculating effect evident with the first quantity of metal soon disappeared and no further proof of its usefulness could be found.

In order that the fullest information would be available when the proposed alteration in metal was begun, it was previously decided to have on record full details of the ordinary metal, so that a true comparison could be made when the alteration was carried out. The information sought was the physical properties, including transverse strength, deflection, tensile strength, impact value and hardness, the micro-structure in thin and thick sections, the chill effect as shown by the wedge test, and the shrinkage effect as determined by a standard 4 in. square block. It was felt that, with all these factors detailed, the authors would be in a position adequately to determine a true comparison. Table I gives in percentage value the increase in properties from the results of tests made.

TABLE II.

CHEMICAL PROPERTIES OF INOCULATED CUPOLA METAL COMPARED WITH ORDINARY CUPOLA METAL DERIVED FROM 15 TESTS ON EACH METAL.

| | Ordinary Cupola Metal. | | Inoculated Cupola Metal. |
|---|---|---|---|
| T.C. | 3·51 | .. | 3·24 |
| Gr. | 2·90 | .. | 2·66 |
| C.C. | 0·61 | .. | 0·58 |
| Si | 1·80 | .. | 2·05 |
| S | 0·085 | .. | 0·091 |
| P | 0·71 | .. | 0·54 |
| Mn | 0·80 | .. | 0·75 |
| Si (without inoculant) | — | .. | 1·63 |

The materials used previous to inoculation were a high phosphorus iron, two grades of low phosphorus iron (about 0·3 to 0·4% phosphorus), good-quality machinery scrap and return scrap. Similar irons were used after conversion to the inoculated metal, with the machinery scrap displaced by steel scrap, so that a carbon content between 3·2 and 3·3% was available. No special pig irons were used throughout this investigation. The corresponding analysis is shown in Table II, where the comparative figures of 15 tests are given. The reduced silicon content previous to inoculation was found necessary to obtain maximum benefits from inoculation. The incorporation of steel scrap has also tended to reduce the phosphorus content somewhat.

It was believed that inoculation would simplify cupola practice, especially in foundries where a wide range of section size was handled and castings produced with other special properties, for which it was necessary to make several mixtures to suit requirements. It has been found that the metal is suitable for a much wider range of castings than any one of the former grades used. It is able to produce a strong grey structure in thin sections and a satisfactory close-grain structure in heavy sections. Later experience has shown that, by the use of various quantities of inoculant the metal can further extend its usefulness. Although one mixture has not been found to deal with the complete range, the number has been reduced to two, and it is hoped that further experiments will enable the use of one mixture and permit necessary modifications to be made at the spout. The authors emphasise the need for close control to obtain full advantage from inoculated metal.

## SOME USEFUL WARTIME DEVELOPMENTS IN WHITEHEART MALLEABLE IRON

By G. R. WEBSTER, A.M.I.Mech.E., A.M.I.Mar.E.

IN this paper the author describes the manufacture of some types of tracks used in tank construction. As with many other types of tank castings, a large proportion are being made in whiteheart malleable cast iron. The foundry problems associated with their production are similar to those of other whiteheart malleable castings, the main difference being that whereas a large percentage of ordinary malleable castings are machined, the track links are not machined at all, apart from reaming the pinholes. For this reason the tolerance permitted is very small, indeed the patterns and coreboxes necessary are machined to a tolerance of ± 0·004 in. The pattern work, moulding and coremaking, are described, and reference is made to the melting of the metal. Cupolas are used, and they are equipped with receivers. The chemical composition of the molten metal is controlled within the following limits :—

| T.C. | Si. | Mn. | S. | P. |
|---|---|---|---|---|
| 2·9-3·1 .. | 0·55–0·7 .. | 0·25–0·3 .. | 0·16–0·2 .. | 0·1 max. |

A typical cupola charge comprises 68% scrap from the foundry, 10% hematite or refined pig iron ; 1% ferro-silicon (13% Si), and 21% steel scrap. Measured with an optical pyrometer, the temperature of the metal at the receiver spout is between 1,400° and 1,430° C.

The malleabilising of the castings is carried out in a town's gas-fired tunnel annealing furnace, maintained at a temperature of 980° C. for 80 to 100 hours, according to the sectional thickness of the castings. The ore ratio in the packing medium is varied between 1 to 5 and 1 to 8, again according to sectional thickness.

Earlier types of track-link castings were given a cyanide hardening to produce a hard surface with a toughened core, but this process was quickly discontinued in favour of an oil quench from 780° C. The castings were brought to the hardening temperature in salt-bath furnaces. With the object of improving the wearing properties of the castings, the pin-holes were cast smaller and after malleabilising were drilled to normal

size to take the pin. The reason for this was to remove the ferritic layer, which is relatively unchanged by the oil-hardening process; by its removal the fine pearlite and temper-carbon is reached, which is affected by the oil-hardening process, giving a harder zone on which the hardened and ground pin can actuate.

TABLE I.

EFFECT OF VARIOUS HEAT-TREATMENTS ON THE PHYSICAL PROPERTIES OF B.S. TEST-BARS.

| | Temperature, °C. | Yield Stress, Tons per Sq. In. | Max. Stress, Tons per Sq. In. | Elongation, % | Bend Test. | V.P.N. Hardness 30-kg. Load. |
|---|---|---|---|---|---|---|
| As annealed ..... | — | 16·3 | 26·15 | 9·7 | 180° | 148 |
| Oil quenched, 750° C. | — | 21·65 | 31·7 | 7·75 | 143 | 180 |
| " " 750° C. | 450 | 19·4 | 30·6 | 9·5 | 180° | 181 |
| " " 750° C. | 600 | 17·95 | 29·05 | 9·2 | 180° | 158 |
| " " 800° C. | — | 27·3 | 33·95 | 5·2 | 98 | 203 |
| " " 800° C. | 450 | 24·7 | 33·7 | 6·80 | 154 | 201 |
| " " 800° C. | 600 | 22·25 | 32·7 | 7·5 | 180° | 187 |
| " " 850° C. | — | 28·5 | 36·85 | 6·00 | 100 | 207 |
| " " 850° C. | 450 | 26·95 | 34·7 | 5·5 | 148 | 214 |
| " " 850° C. | 600 | 24·6 | 33·45 | 7·5 | 180° | 191 |
| " " 900° C. | — | 31·4 | 36·2 | 4·0 | 63 | 218 |
| " " 900° C. | 450 | 30·0 | 37·65 | 5·5 | 64 | 219 |
| " " 900° C. | 600 | 27·1 | 35·95 | 7·2 | 180 | 210 |
| " " 950° C. | — | 32·75 | 39·2 | 4·5 | 53 | 234 |
| " " 950° C. | 450 | 30·6 | 36·5 | 4·00 | 87 | 218 |
| " " 950° C. | 600 | 27·3 | 34·5 | 5·7 | 180° | 210 |

° Not broken.

An experiment was carried out to determine the effect of various quenching temperatures, and subsequent tempering for 2 hours at 450° C. and 600° C. respectively. For this purpose, a sufficient number of B.S. tensile and bend bars were cast from the same tap of metal from the cupola, with the following analysis:—T.C. 2·86; Si, 0·56; Mn, 0·21; S, 0·189; and P, 0·061%. All these test-bars were annealed together for approximately 160 hours at 980° C. with an ore ratio of 1 : 5.

The annealing time of 160 hours is rather more than the normal commercial practice of producing a good whiteheart malleable iron, but it was thought advisable in this instance in view of the high quenching temperatures employed for the subsequent heat-treatment. For this reason the yield stress of the annealed test-bars obtained was rather lower than with the normal annealing practice.

A carbon analysis was made from the "centre" of a ⅜ in. bend bar after annealing, which was as follows:—T.C, 1·24; C.C., 0·43; and G.C., 0·81%. The physical properties obtained with these various heat-treatments are shown in Table I, representing the average figures of four test-bars.

## SPEED AND ROTATION IN THE CENTRIFUGAL CASTING PROCESS

By J. E. Hurst, D.Met.

IN this paper Dr. Hurst reviews the conditions of rotational speed adopted in the various types of centrifugal casting processes which have been proposed or adopted commercially. It is evident that in each type of process differences exist in the speed conditions adopted by individual operators. In spite of these, at least two notions of principle governing the speed conditions exist, running through the whole of the records and recommendations.

The first and perhaps the earliest, notion is that of the choice of a speed to obtain an approximately constant condition of tangential or centrifugal force during rotation. The predetermined conditions of tangential force recommended have been fixed somewhat arbitrarily, but in general based upon practical experiment. They are variously expressed in the paper, from which it will be appreciated that the peripheral velocity will vary with the diameter of the castings. The density of the molten metal is also a factor in these considerations.

An alternative notion is that of the choice of a speed of rotation to conform to a uniform predetermined peripheral velocity. Here again the predetermined velocity has been based upon practical experiment and has been governed by some such consideration as the uniformity in radial wall thickness or by some relationship to the pouring considerations. The rotational speed, in that it plays an important part in the acceleration of the molten metal delivered to the mould, depends very frequently on the method and conditions of pouring, the nature of the mould and the characteristics of the liquid metal. It is such considerations which account for many of the differences in speed conditions adopted by individual processes. In the case of true centrifugal casting about the vertical axis, a substantial increase in the theoretical speed calculated to give a required internal form in bronzes has been found necessary. The differences in speed requirements consequent upon the use of metal moulds as opposed to sand moulds in rotation about the horizontal axis has been observed, and attention has been drawn to the interconnection between the conditions of pouring in so far as velocity, rate and direction are concerned and speed of rotation. In the case of semi-centrifugal and pressure castings, in general, lower speeds of rotation are used. In these cases the characteristics of the mould are of considerable importance in determining the maximum speed that can be adopted with safety.

## RELATIONSHIP OF BRINELL HARNESS AND YIELD STRESS IN CERTAIN CAST STEELS

By T. W. Ruffle.

A GENERAL relationship between Brinell hardness and ultimate stress is widely recognised and used by engineers and metallurgists. In connection with tests in the foregoing paper, therefore, it was decided to examine this relationship, and the following points were investigated in detail:—(1) The Brinell hardness number and ultimate stress of separately cast test-pieces; (2) the yield ratio of the test-pieces; (3) the Brinell hardness number and yield stress of the test-pieces; and (4) the agreement in Brinell hardness number between test-pieces and castings.

As a result of this investigation the author concludes that:—(1) The yield-point and ultimate stress of carbon-manganese steel, heat-treated and tested, as described, can be estimated by the formula:—

$$\text{Y.P.} = \text{B.H.N.} \times 0{\cdot}08 + 12{\cdot}56$$
$$\text{U.S.} = \text{B.H.N.} \times 0{\cdot}15 + 13{\cdot}32$$

with an accuracy of ± 1 ton per sq. in. for the former and ± 1·5 tons per sq. in. for the latter. (2) In order to guarantee a minimum yield-point of 26 tons per sq. in. the minimum B.H.N. must be $(26 + 1) = x \times 0{\cdot}08 + 12{\cdot}56 = 180$. This corresponds to a minimum ultimate stress of 40·3 ± 1·5 tons per sq. in. (3) In the same way, it is necessary to establish a maximum ultimate stress; allowance should be made for the normal variation of ± 1·5 tons per sq. in. (4) It is emphasised that these results apply only to the type of steel under consideration in the condition described.

*(Reference will be made to further papers in our next issue.)*



the micro-balance employed. A considerable amount of heat. The potential difference between the electrodes

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*THE teaching of up-to-date methods in chemistry, discussed in a recent number, is often stated to be impossible, at least to the extent that is desirable, because of the prohibitive cost of the complete range of apparatus necessary. One method of overcoming this has been suggested in a recent letter to a contemporary, which recommends that scientific instrument makers should encourage the destruction of older apparatus, and its replacement by newer models. While this could be carried to extremes, it is worth bearing in mind. However, it should also be remembered that much good work can be and has been done with apparatus that was not "streamlined" and highly polished. It would be wrong to overlook the potentialities of, say, the polarograph in a present day students' course, but equally wrong to plead that because the only available model was home-made and non-recording it was useless or old-fashioned. Again, some instruments, as long as they function, never really "date." Such are the spectrograph and the microscope. And in passing, why is the microscope so sadly neglected in training? We ourselves were caused much unnecessary labour because, while biologists were made at home with the microscope and physicists were given a reasonable working knowledge of its potentialities, we poor chemists had no hint that it could have the remotest chemical interest. Use modern apparatus by all means. But make sure that the old apparatus is really ready to be scrapped.*

# Micro-Electrolytic Methods of Chemical Analysis

By Henry J. S. Sand, Ph.D., D.Sc., F.R.I.C.

*The deposition of metals from electrolytic solutions on passage of an electric current has long been used to afford a means of gravimetric analysis. A number of the methods which have proved valuable on the ordinary laboratory scale have been adapted to the detection and determination of minute amounts of metals.*

ELECTRICAL methods lend themselves readily to the detection and to the gravimetric estimation of metallic and other substances. Thus, in 1931 H. J. Brenneis[1] employed his so-called electrolytic slides or rods for the detection of traces of silver, copper and zinc. These slides are micro-electrodes consisting of two or sometimes three thin platinum wires which are fused into a glass holder so as to be insulated from each other and to project slightly from the glass. The distance of the electrodes from each other may be as small as 1/10 mm. One electrode is connected to the positive, another to the negative pole of a battery and the slide is brought into contact with a drop of the solution to be examined, absorbed if convenient by a piece of filter-paper. If copper is the metal to be tested for, as small a quantity as one microgram may be recognised by its colour and lustre. A third platinum wire in the electrode may be useful for purposes of comparison. In the case of silver, one-hundredth of a microgram may be detected after converting the deposited metal into sulphide.

In Glazunov's procedure[2] a metallic sample is tested for impurities by making it the anode in a circuit of which an aluminium plate is the cathode. The electrodes are separated by two pieces of "spot-test" paper, of which one rests on the cathode and contains the solution of a conductance electrolyte, such as sodium chloride or sulphate, while the other, placed upon it, holds the reagent for identifying the constituent which has passed into solution from the anode.[3]

Electrochemical methods are also sometimes employed to isolate constituents that are later determined spectrographically. The latter may be conveniently deposited by electrolysis, say, on an amalgamated copper wire, a few drops of test solution being used which are held in a silver or platinum cup.[4]

We are here not discussing the determination of minute quantities of substances by electrolytic Marsh tests or by polarographic analysis, since these subjects are too extensive for incorporation in this review.

Electrolytic methods are very readily applicable to gravimetric estimations on the micro-scale. The limits of accuracy which can be obtained are largely those of

1 *Mikrochem*, 1931, **9**, 385.
2 8th and 11th Congress of Industrial Chemistry, 1929 and 1932.

3 H. J. Brenneis, *Mikrochem.*, 1931, **9**, 385; A. Glazunov, *Osterr. Chem. Ztg.*, 1938, **41**, 217; H. Fritz. Papers in *Z. anal. Chem.* and in *Mikrochemie* from 1929 onwards; E. B. Ashcraft, *Trans. Electrochem. Soc.*, 1940, **78**, 127, and included in this a review and discussion by R. O. Clark; D. L. Masters. METALLURGIA, 1943, **29**, 101.
4 A. Schleicher and co-workers. *Z. anal. Chem.*, 1935, , 241 **101**; 1936, **105**, 393; 1938, **108**, 241; V. Poremski and C. Samie, *Bull. Soc. chim.*, 1939, **6**, 596.



whole apparatus is represented in Fig. 3, the electrodes in Fig. 5, while the separate electrodes and the sup-

the micro-balance employed. A considerable amount of work has also been done in recent years on the so-called semi-micro scale. In this, ordinary analytical balances of high precision are employed, weights being calculated from three successive deflections of the swinging balance.[5] A precision ranging down to 10 micrograms is said to be thus attainable.

The first application of microchemical methods to gravimetric electrolytic analysis appears to have been made by E. Jänecke[6] in 1904, who determined mercury by deposition on a gold wire, a Nernst quartz fibre balance being used. General recognition of the promise held out by the micro-method followed the publication

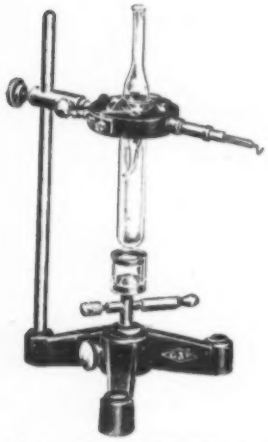


Fig. 1.—Pregl Electrolysis Apparatus.

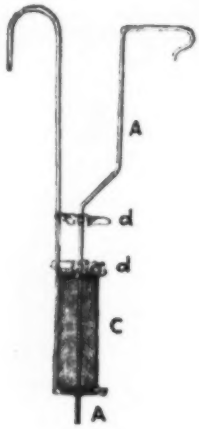



Fig. 2.—Pregl Electrodes.

of Pregl's book on "Quantitative Organic Micro-Analysis."[7] Instructions are there given for the determination of traces of copper, particularly in tinned vegetables. All organic material having been completely destroyed, the copper is collected in a sulphuric acid solution and determined in the apparatus about to be described. The latter is shown in Figs. 1 and 2. The electrolysis vessel is a test tube of 16 mm. external diameter and 105 mm. length, in which the electrolyte is kept boiling during electrolysis. Resting on its top there is seen a vessel filled with cold water, which acts as a reflux condenser. The pair of electrodes is shown in Fig. 2. The cathode C has a length of 30 mm. and a diameter of 10 mm. It carries three glass beads both at the top and the bottom, to prevent it from scraping the test tube. The anode A is fashioned from a platinum wire of 130 mm. length. Its tip rests on the bottom of the test-tube, and it is maintained in a central position by means of glass distance pieces *d*. The tops of the cathode and anode leading-in wires are bent round in order to make connection with the circuit by means of mercury cups. The volume of the electrolyte is about 7 ml. After a determination, the tip of the cathode wire is ignited to expel any trace of mercury that may adhere to it. The liquid undergoing electrolysis has a height of 35 mm. to 40 mm., a sheet of mica being accommodated outside the test-tube above the top of the liquid to protect the upper part of the stand from heat. The potential difference between the electrodes is about 2 volts. The liquid is kept boiling during electrolysis, all bumping being prevented by the oxygen liberated at the anode. Complete deposition, which may be tested for by means of ferrocyanide, requires from 10 to 20 mins. Before disconnecting, the electrolyte is brought to room temperature by swinging the holder of the test-tube aside and introducing a beaker of cold water from below without interfering with the current. A second beaker may be used after a few minutes. When the electrolyte is cold the condenser is removed and first the anode and then the cathode is carefully withdrawn. The cathode is dipped successively into distilled water, alcohol and ether and dried at a height of about a metre over a Bunsen flame. All simple depositions, such as that of mercury, which can be carried out at boiling temperature, may be performed in the same way with excellent results.

A. A. Benedetti-Pichler[8] extended the range of electrolytic micro-determinations by working at temperatures slightly below the boiling point. He was thus able to employ solutions containing nitric acid and to effect separations of copper from metals which would have been deposited by Pregl's technique from a solution free from nitric acid. It was sometimes necessary to add a crystal of potassium sulphate to initiate the deposition of copper, and also to reduce the acidity of the solution with ammonium hydroxide. Spraying, due to the action

Fig. 3.—Clarke-Hermance Electrolysis Apparatus.

Fig. 3a.—Clarke-Hermance Electrodes.

of the anode, was prevented by the addition of a few drops of alcohol. A considerable number of alloys was thus analysed on the micro-scale.

As showing the limits to which the delicacy of micro-determinations can be pushed, we refer to experiments by E. Wiesenberger,[9] who employed a special electromagnetic micro-balance, sensitive to 0·015 microgram, and was able to make copper determinations on specimens weighing from 6 to 13 micrograms.

Among attempts to increase the range and accuracy of electrolytic micro methods, we mention particularly the work of B. L. Clarke and H. W. Hermance.[10] Apparatus was designed in which both electrodes a platinum gauze cylinders that are held in a specially designed glass frame-work. The construction of this frame is such that very efficient circulation of the electrolyte is produced by a current of gas which is blown through the liquid. The cell has a fused-on water jacket, with a thermometer tubulure and a tubular loop for heating the water by means of a micro-burner. The

5 A. A. Benedetti-Pichler, *Ind. Eng. Chem.*, Anal. Ed., 1939, **11**, 226.
6 *Z. anal. Chem.*, 1904, **43**, 547.
7 Translation by Fyleman, 1924, p. 158.
8 *Z. anal. Chem.*, 1923, **62**, 321.
9 *Mikrochem.*, 1931, **10**, 10.
10 *J. Amer. Chem. Soc.*, 1932, **54**, 877.

whole apparatus is represented in Fig. 3, the electrodes in Fig. 3A. It will be seen that the cell is fitted with a tap by the use of which the electrolyte can be withdrawn and replaced by water at the end of a determination.

The method of separating one metal from another by control of the cathode-potential was extended to micro-electrolytic analysis by A. J. Lindsey and H. J. S. Sand[11] in 1935. In macro-electrolytic determinations efficient separations require the employment of an auxiliary electrode. In micro-electrolytic separations, however, the use of anauxiliary electrodeis undesirable, and the potential of the cathode must be controlled by measuring the potential difference between the anode and the cathode by means of a voltmeter. In order that the method may yield satisfactory results, special arrangements are made to keep the anode-potential as constant as possible. This is attained by the use of depolarisers and by employing a relatively large anode to surround the cathode. A special study of the efficiency of various depolarisers was made, and the use of hydrazine sulphate or of hydroxylamine hydrochloride was recommended. It was found that these depolarisers in small concentration reduce the polarisation of the anode at ordinary temperature by about 1·3 volt, the depolarising efficiency being very slightly improved by rise of temperature and being only slightly affected by current density. Owing to the small current densities required in micro-determinations the potential difference due to ohmic resistance in the electrolyte is small, and its variations during a determination need not cause anxiety.

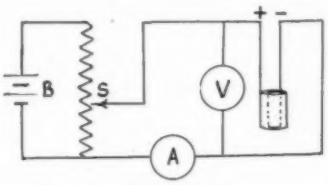



**Fig. 4.—Circuit for controlled cathode-potential.**

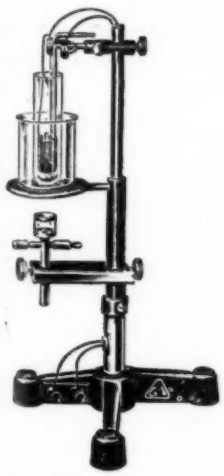


**Fig. 5.—Lindsey-Sand Electrolysis Apparatus.**

The current is controlled by means of the circuit shown in Fig. 4, in which A is an ammeter of range 0 to 1 amp. and V a voltmeter of range 0 to 3 volts. It will be seen that any voltage from 0 to that of the battery B may be tapped off by moving the slider S. Both electrodes are held in a glass frame, the outer—usually the anode—being permanently fastened to the frame, whereas the inner one—which is a Pregl cathode with the glass beads removed—can be dropped into position. Gas-stirring through a nozzle forming part of the frame is provided for, so that a boiling temperature can be dispensed with. The volume of the electrolyte is about 12 ml. A view of the complete stand is given in Fig. 5, while the separate electrodes and the supporting glass frame are shown in Fig. 6. Fig. 7 represents the appliance by means of which dry air heated in a glycerine-water bath serves to dry the electrode after a determination. Fig. 8 shows a convenient tool for carrying the electrode and placing it without handling across the hooks of the balance.

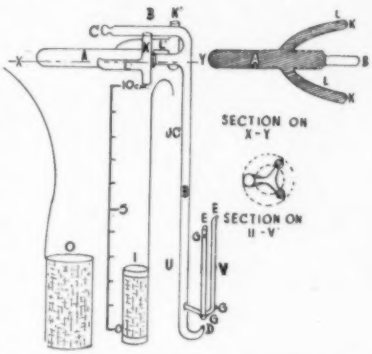



**Fig. 6.—Electrodes and supporting glass frame.**

With these electrodes, bismuth and lead have been separated from a solution containing both metals and determined separately. A special study has also been made of the deposition of metals from chloride solution, a matter of much importance in the analysis of alloys.

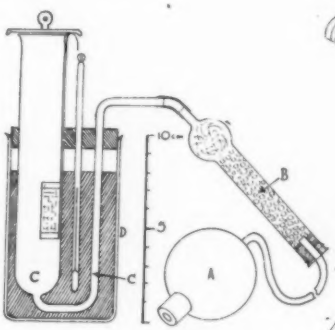


**Fig. 7.—Electrode drier.**

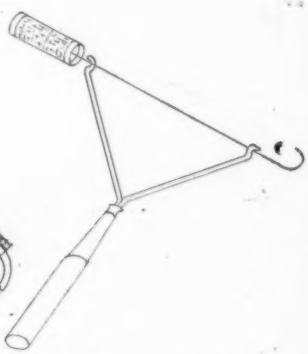


**Fig. 8.—Electrode carrier.**

Thanks are due to Messrs. Griffin and Tatlock, Ltd., from whose catalogue Figs. 1, 2, 3, 3a and 5 are reproduced.

## The Separation and Determination of very small amounts of Aluminium and Iron in Water

THE determination of aluminium in raw and alum dosed waters, containing about 1 p.p.m. of aluminium, and final treat boiler-feed water containing 0·005–0·1 p.p.m. of aluminium, is considered by Stafford and Wyatt.* The aurintricarboxylate method and the hæmatoxylin method are discussed, and reference is also made to the difficulty of separating iron from small amounts of aluminium.

In the method developed by the authors the iron is separated, and determined, if necessary, by the thiocyanate method; the separation being effected by

11 *Analyst*, 1935, **60**, 739.

* *The Analyst*, **68**, 1943, pp. 319—324.

extracting the thiocyanate with a mixed solvent consisting of amyl alcohol and ethyl ether.

The aluminium is then determined in the extracted solution either by the aurintricarboxylate or the hæmatoxylin method. Both these methods have been modified so that it is possible to determine 0·1–0·5 p.p.m. of aluminium to an accuracy of ± 0·05 p.p.m., or 0·01–0·10 p.p.m. of aluminium to an accuracy of within ± 0·01 p.p.m., provided that the amount of iron originally present does not exceed about 10 times that of the aluminium content. The modified hæmatoxylin method is rather more convenient and slightly more sensitive than the modified aurintricarboxylate method.

Both methods can be used to give an accurate colorimetric measure of the total iron and aluminium content (expressed as Al) of a water sample.

## Micro Boiling-Point Determination

THE determination of the boiling point of a liquid on the micro scale has been described by Emich,[1] and his method is now one of the best known and most widely used microchemical operations. A small air bubble is sealed into a capillary of 0·6–1·2 mm. diameter with a hair tip, below the liquid, as shown in Fig. 1 (*a*), and the boiling point is noted as the temperature at which the drop of liquid rises above the bath liquid to the position indicated in Fig. 1 (*b*). Since the success of the operation, performed according to the Emich method, is dependent on the presence of the tiny air bubble, it is obvious that the boiling point at reduced pressure cannot be determined in this fashion. Recently, it has been shown that by using a finer capillary of 0·3 mm. diameter[2] it is not necessary to have the hair tip or the air bubble. With an ordinary type capillary (Fig. 2 (*a*)) the author employs an electric heater on which the capillary is laid, and the boiling point is indicated by the coincidence of the lower meniscus of the liquid bubble with the edge of the heating surface (Fig. 2 (*b*)).

(a) (b)

**Fig. 1.—Emich Method.**
**(a) Beginning of determination. A tiny air bubble is sealed below the liquid.**
**(b) At the boiling point the liquid rises in the direction of the arrow, away from the bath.**

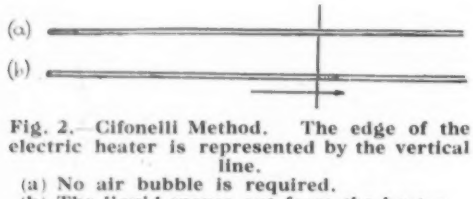
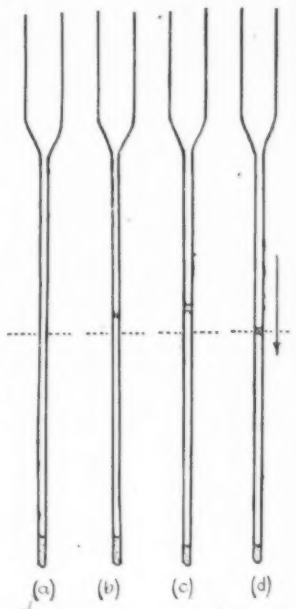


**Fig. 2.—Cifonelli Method. The edge of the electric heater is represented by the vertical line.**
**(a) No air bubble is required.**
**(b) The liquid moves out from the heater.**

It seems possible that this method could be adapted to reduced pressure work, but it is of interest that the problem has been solved by a slightly different variation.[3]

The boiling-point tube, as shown in Fig. 3 (*a*) is, at the operating end, a normal capillary of 1 mm. diameter, while suction may be applied through the wide end. The capillary is heated in a bath which has the thermometer bulb just below the surface of the bath liquid and close to the capillary. As the boiling point of the liquid under test is approached, liquid condenses above the bath level, as shown in Fig. 3 (*b*). This, when the boiling point has been passed, forms a complete seal across the capillary (Fig. 3 (*c*)), and at this stage the temperature of the bath is allowed to fall slowly. The liquid slides downwards in the capillary, and the boiling point is the temperature at which the lower meniscus falls, as in Fig. 3 (*d*), just below the bath liquid surface.



(a) (b) (c) (d)

**Fig. 3.—Garcia Method.**
**(a) Beginning of estimation.**
**(b) Condensation commences.**
**(c) Complete drop formed and removed.**
**(d) Drop moves towards the bath.**

Not only does this method work satisfactorily for reduced pressures, but it compares favourably at atmospheric pressure with the Emich method, as shown by the (uncorrected) temperatures in the following table :—

| | Emich Method. | | Garcia Method. |
|---|---|---|---|
| Carbon tetrachloride ..... | 76·5° | .. | 76·0° |
| Benzene ..... | 80·0° | .. | 80·0° |
| Aniline ..... | 181·5° | .. | 181·0° |

The device represents a very simple and satisfactory solution to a difficult but pressing problem.

1 F. Emich. *Lehrbuch der Mikrochemie*, 2nd ed., 1926, p. 51; F. Emich-F. Schneider. *Microchemical Laboratory Manual*, 1932, p. 32.
2 T. Cifonelli. *Ind. Eng. Chem., Anal. Ed.*, 1944, **16**, 134.
3 C. R. Garcia. *Ind. Eng. Chem., Anal. Ed.*, 1943, **15**, 648.

## Micro-Electrolysis

Dr. Sand's article in this issue is to be followed next month by an article dealing with the application of a specialised branch, internal electrolysis, to small amounts of material.

METALLURGICAL DIGEST



# Stress-Strain Measurements in the Deep Drawing of Cylindrical Cups

By E. J. Bartholomew

CUP-WALL stresses are determined for various blank diameters. The tensile stress in the cup wall for the maximum diameter blank is compared with the actual stress from the tensile test and the tensile test data are reported in the form of the s-q′ plot. Strain measurements are made in the cup walls. The maximum blank diameter for a metal in a set of press conditions represents the limit of durability of that metal, and since the tensile test data can be used to determine this blank diameter, then, in effect, they are an index of the drawability of the metal.

TABLE I.
STRESSES AND STRAINS IN CUP WALL.

| Material. | Max. Tensile Stress in the Cup Wall, Tons per Sq. In. | Tensile Stress Corresponding to Max. Uniform Strain, Tons per Sq. In. | Maximum Uniform Strain. qu′ |
|---|---|---|---|
| Half hard 65–35 brass | 32·85 | 32·72 | 0·20 |
| Annealed 65–35 brass | 31·07 | 30·85 | 0·39 |
| S.A.E. 1010 deep drawing sheet .... | 25·31 | 26·39 | 0·25 |
| Hard 2S aluminium | 10·49 | 11·03 | 0·03 |
| Annealed 2S aluminium ..... | 7·32 | 7·19 | 0·21 |

The first tests were run on S.A.E. 1040 deep-drawing sheet steel, 0·063 in. thick, with Rockwell hardness 42B, which is equivalent to 82F on the conversion chart. Although reasonable agreement between cup wall stresses and tensile test values was found (Table I), it was considered that thicker material might allow for better accuracy of stress measurement. In addition, by using a thicker material any influence which thickness might have on the results could be observed. The second set of tests, therefore, were run on 65–35 half-hard brass, 0·10 in. diameter, with a Rockwell hardness 100F. To determine how a change in temper of the same material might affect the test, a third run was made, using 65–35 brass of the same thickness, annealed at 565° to 593° C., and having a Rockwell hardness of 61F. The fourth and fifth tests were conducted on hard and soft aluminium, 0·10 in. diameter, having Brinell hardness of 44 and 20 respectively.

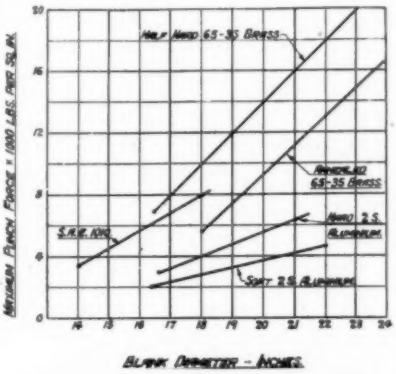



**Fig. 1.—Relationship between maximum punch force and blank diameter for the given press conditions.**

Tests were made to determine stressed strain values of the various metal-drawing into cylindrical cups, and also stress-strain values in tension. The drawing of the cups was conducted in a sub-press designed to operate in a testing machine so that punch forces could be measured. Curves were drawn, showing the relationship between maximum punch force and blank diameter (Fig. 1), and the relationship between cup-wall stress at the critical section and blank diameter (Fig. 2).

From the correlation in all cases between maximum in the cup wall at the critical section and actual stress from the tensile test representing maximum load or limiting uniform deformation, the following conclusions may be drawn :—

1. A "critical section" exists in the drawn cup wall, at which location failure will occur for the given set of press conditions when the limit of drawability of the metals is reached.

2. The limit of drawability may be satisfactorily indicated by the maximum blank diameter which may be drawn without local necking or failure at the critical section.

3. The maximum blank diameter representing the limit of drawability for the metal may be accurately and consistently determined within 0·05 in. for any given set of conditions.

4. Definite correlation exists between the maximum stress in the critical section of the cup wall at maximum drawability and the actual stress for the tensile test at maximum load or limiting uniform deformation.

5. Reasonable agreement exists between the breaking stresses at the critical section and actual breaking stresses from the tensile test.

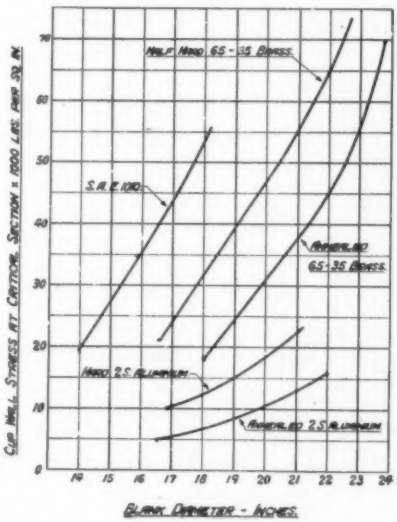



**Fig. 2.—Relationship between clip wall stress at critical section and blank diameter.**

6. Limiting uniform strain, qu′, shows a more definite relationship to maximum percentage reduction in cupping than to the common elongation value measured in 2 in.

From *Trans. American Society of Metals*, 1943, vol. 31, Sept., pp. 582–593.

7. For the given set of press conditions, a linear relationship exists between punch force and blank diameter.

8. The maximum blank diameter which is a sensitive indication of the "drawability" of the material, may be accurately determined from the tensile test for any metal once the press conditions are established.

# Effects of Minor Alloying Elements on Aluminium Casting Alloys

## By W. Bonsack

THE American Society for Testing Materials Specifications discussed, as the result of exhaustive investigations made by the National Smelting Co., Ltd., Ohio, include four groups of alloys, three of the aluminium and silicon type and one of aluminium-magnesium and aluminium-zinc-magnesium type. The first group consists of specifications for sand, chill and diecast 5% silicon alloys and the second group includes the 13% silicon alloy specification for the same methods of casting. These two groups represent the simple binary aluminium-silicon alloys, while the third group consists of the complex aluminium-silicon alloys and includes the ternary, quaternary, and even more complex alloys in present-day use. The fourth group deals with the aluminium-magnesium alloy specifications. In Table I are given the analysis and some of the physical properties of the alloys considered.

In the silicon alloys containing 4·5 to 6·0% silicon, iron is limited to 0·8% in sand and permanent mould castings and to 2% in die-castings, because it forms large needles and plates of an iron-aluminium-silicon complex which rapidly reduces the alloy's ductility. The effect of iron on the corrosion resistance of 5% silicon alloys is negligible, as alloys containing 1·49 to 2·53% of iron showed no detrimental change after 10 years' exposure to a salt-water atmosphere. Copper is limited to 0·1% in two alloys, to 0·4% in other two alloys, and to 0·6% in the fifth. The reasons for the low limits of copper in the first two alloys is the higher corrosion resistance desired in these alloys. Advantages gained by small copper contents in the 5% silicon alloy are improved machinability, improvement of resistance to vibration and increase in tensile strength and yield-point without marked reduction in ductility. Magnesium in silicon alloys acts as a powerful hardener, so that wherever ductility is required it should be limited to 0·05 to 0·1%.

In the two "high pure" 5% aluminium-silicon alloys, manganese is limited to 0·03%, and in the other three alloys to 0·3%, although manganese in general improves both the mechanical properties and corrosion resistance of the alloy containing it. The properties derived from the addition of nickel to 5% aluminium-silicon alloys are to increase the tensile strength, yield-point and proportional limit, and to reduce slightly the elongation and impact strength. In the sand-cast and chill-cast alloy specifications, nickel is included in the "other impurities" (0·10% maximum), while in the die-casting specification, nickel is allowed to be present up to 0·5%. Zinc is kept rather low in 5% aluminium-silicon alloys. The die-casting alloy allows 0·5%, while the commercial sand and permanent mould castings alloys allows only 0·2 and 0·3% respectively. Zinc is kept to these low limits because it is said to increase corrodibility.

As in other binary aluminium-silicon alloys, iron in the 13% silicon alloy is the most undesirable element present. It forms a ternary eutectic with aluminium and silicon at 12·5% silicon, 0·5% iron, and 87%

From *Bulletin Amer. Society for Testing Materials* 1943, Oct., No. 124, pp. 41–51.

TABLE I.—COMPOSITION AND PHYSICAL PROPERTIES OF A.S.T.M. ALUMINIUM SILICON ALLOYS.

| A.S.T.M. Specifications. | Alloy. | Cast. | Composition. | | | | | | | | | Elongation. | | Tensile Strength. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Cu. | Fe. | Si. | Mg. | Mn. | Zn. | Ni. | Cr. | Ti. | Minimum. | Typical. | Minimum. | Typical. |
| B26 –41T | J | S | 0·4 | 0·8 | 5·0 + 1·0 − 0·5 | 0·05 | 0·3 | 0·2 | — | — | 0·2 | 3·0 | — | 7·6 | — |
| B26 –41T | JJ | S | 0·1 | 0·8 | 5·0 + 1·0 − 0·5 | 0·05 | 0·05 | 0·05 | — | — | 0·2 | 3·0 | — | 7·6 | — |
| B108–41T | 9 | P | 0·4 | 0·8 | 5·0 + 1·0 − 0·5 | 0·05 | 0·3 | 0·3 | — | — | — | 2·0 | — | 9·4 | — |
| B108–41T | 9A | P | 0·1 | 0·8 | 5·0 + 1·0 − 0·5 | 0·05 | 0·05 | 0·05 | — | — | — | 2·5 | — | 9·4 | — |
| B85 –39T | IV | D | 0·6 | 2·0 | 4·5 − 6·0 | 0·1 | 0·3 | 0·5 | 0·5 | — | — | — | 3·5 | — | 12·9 |
| B26 –41T | K | S | 0·15 | 0·8 | 12·5 + 0·5 | 0·05 | 0·2 | 0·1 | — | — | — | 5·0 | — | 10·7 | — |
| B108–41T | 8 | P | 0·3 | 0·8 | 11·0 + 1·0 | 0·05 | 0·5 | 0·3 | — | — | — | 3·0 | — | 12·0 | — |
| B85 –39T | V | D | 0·6 | 2·0 | 11·0 − 13 | 0·1 | 0·3 | 0·5 | 0·5 | — | — | — | 1·5 | — | 14·7 |
| B26 –41T | N | S | 1·25 + 0·25 | 0·5 | 5·0 + 0 | 0·5 + 0·1 | 0·1 | 0·05 | — | — | 0·2 | — | — | — | — |
| B85 –39T | VI | D | 1·5 − 2·5 | 2·5 | 2·5 − 3·5 | 0·1 | 0·3 | 0·8 | 0·5 | — | — | — | 3·5 | — | 13·4 |
| B85 –39T | XI | D | 1·0 − 3·0 | 2·0 | 7·0 − 9·0 | 0·1 | 0·3 | 0·5 | 0·5 | — | — | — | 1·7 | — | 14·3 |
| B26 –41T | M | S | 0·2 | 0·5 | 7·0 + 0·5 | 0·3 + 0·1 | — | 0·05 | — | — | 0·2 | — | — | — | — |
| B108–41T | 10 | P | 0·2 | 0·5 | 7·0 + 0·5 | 0·3 + 0·1 | 0·05 | 0·05 | — | — | — | — | — | — | — |
| B108–41T | 6 | P | 1·0 + 0·5 | 1·3 | 12·0 + 1·0 | 1·0 + 0·25 | 0·05 | 0·1 | 2·5 + 0·5 | — | — | — | — | — | — |
| B108–41T | 7 | P | 1·5 + 0·5 | 0·9 | 12·25 + 0·75 | 0·55 + 0·15 | 0·75 + 0·15 | 0·4 | 0·05 | — | — | — | — | — | — |
| B26 –41T | L | S | 0·1 | 1·4 | 0·25 | 3·75 + 0·5 | 0·6 | 0·05 5 + 0·7 | — | — | 0·2 | 6·0 | — | 9·8 | — |
| B26 –41T | D | S | 0·2 | 1·0 | 0·6 | 0·5 + 0·1 | — | −02 | — | 0·5 + 0·1 | 0·2 + 1·0 | 3·0 Aged | — | 13·4 Aged | — |

S—Sand cast. P—Permanent mould. D—Die-cast.

aluminium, and any amount over 5% iron is present in large needles of aluminium-iron silicide which up to 0·8% increases strength and hardness, but above 0·8% causes the strength and elongation to decrease rapidly. The A.S.T.M. specification for sand and permanent mould castings limits the iron at the proper amount, but for die-castings the limit seems too high. Corrosion tests carried out on 13% silicon alloys containing 1·35 to 4·34% of iron showed little choice between 1·35 and 1·9% of iron as far as corrodibility was concerned, but it was apparent that the alloy containing lower iron had the higher initial properties.

Copper in the 13% alloy is kept at lower limits in the sand-casting and chill-casting specifications than in the 5% silicon alloy, but the copper in the die-casting specification remains the same in both alloys. The corrosive influence of copper is considerably overrated as corrosive tests showed that alloys containing 0·64 to 0·98% copper did not lose any more of their properties during a five-year saltwater atmosphere test than did alloys containing about 0·15% copper. Magnesium in the 13% alloy changes the properties in the same manner as in the 5% alloy, and its limitation to 0·05% in all types of castings is desirable. There is hardly any ageing effect whether 0·12, 0·09, or 0·01% of magnesium is present in the alloys. Manganese is limited to 0·2% in sand castings and to 0·3% in permanent mould and die-castings of the 13% silicon alloy, and nickel and zinc to the same amounts as in the 5% silicon alloy.

In 13% silicon alloy tin is allowable up to 0·3% without producing a serious decrease in tensile strength, yield-point and elongation, and lead has little effect between 0·01 and 0·05%. Titanium, which forms an intermetallic compound and crystallises like iron in needle form, reduces tensile strength and elongation rapidly and is therefore limited to 0·2%.

In the binary aluminium-silicon alloys, 5 and 13% silicon, the elements copper, magnesium, manganese, nickel, zinc, iron, lead and tin are mentioned as impurities, but in the complex aluminium-silicon alloys these elements with the exception of iron appear as desirable alloying constituents. Surveying all these alloys, four basic groups can be defined. In the first group are aluminium-silicon alloys to which copper, magnesium, manganese, nickel, titanium, zinc and lead are added individually to form ternary alloys. In the second group, the complex aluminium-silicon-copper alloys form a base for alloys to which these elements are added, and in the third group aluminium-silicon-magnesium alloys have the same additions. In the last group, more complex than the three previous groups, the base consists of aluminium, silicon, copper and magnesium. Typical complex aluminium-silicon alloys are given in Table I.

Alloy M and 10 contain 6·5 to 7·5% silicon, and 0·2 to 0·4% magnesium. The iron content is necessarily limited to 0·5% and the manganese, zinc and other elements to 0·05% each, with the exception of copper, which is allowed to a maximum of 0·2%. This amount is considered low and could be considerably higher without harmful effect, as could also be the zinc, and possibly lead and tin contents. Tests made on this alloy in regard to the effect of iron, titanium and manganese gave interesting results (Table II) and shows that titanium acts as an equivalent amount of iron, and that the deleterious effect of iron and titanium can be considerably minimised or greatly prevented by the addition of manganese. The same is true of the N alloy, where the manganese content is allowed to be 0·1% maximum and the total other elements about 0·2%. In this alloy, which is only used for sand castings, the copper content is between 1 and 1·5% and the silicon content is decreased to 5%. Alloys 6 and 7 contain the highest silicon of the complex aluminium-silicon alloys discussed and are used where high expansion, high strength at elevated temperatures and wear resistance are of importance. The former permits an iron content of 1·3% and the latter 0·9%. Alloy 7 uses about 0·75% manganese to get the same effect of lower expansion and strength at elevated temperatures as 2·5% nickel provides in Alloy 6.

Alloy L is an aluminium-magnesium alloy, with other elements kept at very low limits. Since magnesium in this amount is in solid solution, heat treatability cannot be expected, especially when silicon is below a maximum of 0·25%. The main alloying element in Alloy 0 is zinc instead of magnesium. Magnesium is added in sufficient amounts to form some compound of $MgZn_2$, besides the $Mg_2Si$, and this compound makes the alloy susceptible to ageing treatments, and properties are obtained which usually can only be obtained by solution heat-treatment. Chromium and titanium are also desirable alloying elements in this alloy. A series of alloys containing magnesium and zinc in proportions such as to form a ternary compound of aluminium, magnesium and zinc have been found to have exceptional properties. Alloys containing 6 to 8% of this compound, together with manganese, chromium, titanium and nickel as alloying elements, develop a tensile strength of 16 tons per sq. in. and have an elongation of 14 to 18% in the as-cast condition. When aged at slightly elevated temperatures or solution heat-treated tensile strengths of 16 and 22 tons per sq. in. are obtained with elongation of 4 to 8 and 3 to 5% respectively.

TABLE II.

EFFECT OF IRON, TITANIUM AND IRON ON ALUMINIUM SILICON ALLOY (7% SILICON).

| Alloy. | Fe, % | Ti, % | Mn. % | Yield-point, Tons per Sq. In. | | Tensile Strength, Tons per Sq. In. | | Elongation, % | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 0·48 | 0·03 | 0·02 | 7·0 | 7·6 | 11·9 | 13·1 | 6·0 | 7·0 |
| 2 | 0·48 | 0·18 | 0·02 | 6·4 | 6·9 | 11·8 | 12·4 | 5·5 | 6·5 |
| 3 | 0·46 | 0·18 | 0·32 | 6·2 | 7·0 | 12·5 | 12·9 | 7·0 | 8·0 |

## Separation from the Ore of Molybdenum and Tungsten

TWO important alloy metals, molybdenum and tungsten, occur together in certain ores, but they cannot advantageously be used together. A chemical process for their separation has been patented in the United States. The process is based on the fact that both molybdenum and tungsten react towards certain lighter metals not as bases but as acids. Accordingly, they are separated from the ore by mingling them with a very strong solution of caustic soda, to form sodium molybdate and tungstate respectively. After filtering, the solution containing the two salts is first acidified, then sodium sulphide is added. This forms an insoluble precipitate with the molybdenum, which can be filtered out. The sodium tungstate can either be reduced directly to solid form by evaporation, or converted to insoluble calcium tungstate, which is then filtered out.

*Science News Letter*, February 91, 1944.

# The Canadian White Metal Industry

## A Statistical Survey

THE production of white metals in Canada has seen a very considerable expansion during the last decade or so. Part of this increase is, of course, attributable to the Dominion's very large contribution to the United Nations' war effort, and may perhaps see some recession in the post-war years. Nevertheless, the industry was steadily growing in the pre-war and recent years, as may be seen from the statistical review of this industry in Canada up to 1942, recently received in this country from the Dominion Statistician on which the present account has been based.

WHITE METALS—MATERIALS USED.*

| Material. | Quantity. | Cost at† Works. |
|---|---|---|
| | Lb. | $ |
| *Metals* (Other than Scrap)— | | |
| Aluminium— | | |
| Ingots | lb. 1,267,829 | 255,203 |
| Other forms | lb. 89,953 | 21,506 |
| Antimony metal | lb. 1,818,370 | 264,838 |
| Antimony ore | lb. — | — |
| Arsenic | lb. 49,358 | 3,659 |
| Bismuth | lb. 25,979 | 29,203 |
| Brass and bronze, all forms | lb. 38,355 | 6,989 |
| Cadmium | lb. 347,725 | 368,900 |
| Copper ingots and slabs | lb. 4,470,119 | 520,123 |
| Die-casting alloy | lb. 827,389 | 67,519 |
| Lead, pig | lb. 48,281,959 | 2,413,106 |
| Manganese metal | lb. 38,267 | 19,508 |
| Nickel | lb. 117,244 | 34,095 |
| Silver, fine Troy | oz. 244,869 | 102,108 |
| Tin, pig | lb. 3,059,671 | 1,854,415 |
| Zinc spelter | lb. 26,581,960 | 1,574,019 |
| Other metals, except scrap, but including alloys | lb. — | 569,404 |
| *Scrap Metals*— | | |
| Aluminium | lb. 4,522,083 | 500,596 |
| Brass and bronze, all kinds | lb. 5,469,188 | 464,884 |
| Copper, all kinds | lb. 9,669,323 | 992,895 |
| Lead, battery plates | lb. 13,742,678 | 397,581 |
| Lead, all other kinds | lb. 7,452,200 | 358,491 |
| Zinc, all kinds | lb. 1,746,106 | 74,947 |
| Babbitt | lb. 1,235,253 | 137,649 |
| Solder | lb. 967,967 | 192,168 |
| Tin | lb. 77,432 | 37,018 |
| Type metal | lb. 2,157,237 | 133,366 |
| Drosses | lb. 2,395,208 | 105,595 |
| Other scrap, including scrap unspecified by kind | lb. — | 325,031 |
| Shipping containers | — | 36,138 |
| All other materials | — | 1,467,805 |
| Total | — | 13,328,759 |

* 1942.
† Includes freight, duty, taxes, etc.

The white metal industry in Canada falls into three groups: (*a*) The manufacture of white metal alloys, such as babbitt, solders, type and type metal; (*b*) the refining of scrap to recover white metals, such as lead, tin, zinc, etc.; and (*c*) the manufacture of such articles as lead sheet, lead pipe, antimonial lead, collapsible tubes, slide fasteners, castings, metal foil, etc., in which the white metals or their alloys are the principal constituents.

WHITE METALS—PRODUCTS MADE.*

| Product. | Quantity. | Selling Value. |
|---|---|---|
| | Lb. | $ |
| *Refined Metals* (reclaimed or remelted)— | | |
| Aluminium | 3,981,136 | 711,293 |
| Lead (Antimonial) | 21,917,615 | 1,330,468 |
| Lead (Common) | 7,667,068 | 444,508 |
| Tin | 64,511 | 38,739 |
| Zinc | 1,167,979 | 58,086 |
| *Alloys*— | | |
| Babbitt | 3,994,034 | 1,053,157 |
| Brass | 3,551,905 | 351,524 |
| Bronze | 14,509,498 | 2,235,443 |
| Copper, not elsewhere specified | 4,615,829 | 658,814 |
| Lead, not elsewhere specified | 958,066 | 68,195 |
| Solders | 7,618,416 | 1,840,715 |
| Tin, not elsewhere specified | 13,216 | 5,401 |
| Type and type metal | 4,150,069 | 447,079 |
| Zinc, not elsewhere specified | 3,623,060 | 286,733 |
| Other non-ferrous alloys | — | 82,479 |
| *Castings*— | | |
| Die-castings, all kinds | 23,835,739 | 4,287,215 |
| Other castings— | | |
| Brass and bronze | 1,734,736 | 604,812 |
| Lead | 1,254,582 | 90,333 |
| Other | — | 58,742 |
| *Lead products*— | | |
| Pipe | 6,354,726 | 539,870 |
| Sheets | 4,487,412 | 358,630 |
| Traps and fittings | 1,036,192 | 189,297 |
| Miscellaneous, including bullet wire, shot, etc. | — | 1,237,318 |
| *Scrap and Dross* | 1,045,168 | 33,392 |
| *All other Products*† | — | 6,312,833 |
| Total | — | 23,323,076 |

† Includes foil, collapsible tubes, zipper fasteners, etc
* 1942.

In 1932, 24 plants were in existence in Canada, in which about $4½ million was invested, and they made products worth about $3½ million. By 1938, over $7 million was invested in the industry, and the value of the products was nearly $7½ million, whilst in 1942, the latest year for which complete returns are available, there were 40 plants engaged in this industry, representing a capital of over $12½ million, using over $13 million worth of materials and making products valued at over $23 million at works. This capital is made up of 36% in land, plant, buildings and equipment, 27% in inventories and stocks, and 37% in cash and accounts.

Of these 40 plants, 21 are located in Ontario and are responsible for 76% of output, whilst 19% comes from the 12 plants in Quebec, 5% from two plants in Manitoba and five in British Columbia.

No less striking in the period under review is the increase in the numbers of employees engaged in the industry. In 1932 only 532 were employed, and they earned $621,480, whilst in 1942 a record number of 2,583 were employed with salaries and wages, also a record at $3,848,639.

# Cold Water Spray Quench for Aluminium Alloy Sheet

THE problem of quenching aluminium alloy sheet in heat-treatment has always presented many difficulties in the form of distortion and corrosion resistance. A quench has been developed by a U.S. aircraft corporation which eliminates a great deal of the distortion trouble and produces results which fully meet severe requirements for physical properties and corrosion resistance. The method involves a cold water spray quench which differs from ordinary spray quenches used in the past in that a water-air atomising type nozzle is used which produces a dense fog rather than a spray. A filter system keeps the system consistently clean. Uniformity of quenching which compares favourably with that of an immersion quench is thus obtained.

*The Iron Age*, February 17, 1944.

# Spectrochemical Analysis of Metals with the Multisource Unit

By M. F. Hasler and J. W. Kemp

THE authors have investigated the spectrographic analysis with the multisource unit, a recently developed research tool, of various alloys of iron, aluminium, magnesium, zinc and copper-aluminium. In each case practical working conditions were found which in general represent improvements over those obtainable with conventional arcs or sparks. The authors plan to extend this survey to other alloys and non-metallic materials. The multisource makes available to the analyst an instrument with the following advantages:—

1. Spark-like sources with moderate sensitivity and precision equal to or greater than the standard high-voltage spark units now available.

2. Arc-like sources with high sensitivity, precision approaching that of spark sources, and very little self-absorption, makes it possible to cover a wide range of concentrations accurately.

3. A wide variety of intermediate sources making it possible to effect a reasonable compromise between sensitivity and precision in the solution of any given problem; and making it possible to solve difficult problems arising from the effect of one element on another, differences in metallurgical history of samples, etc.

*Journal of the Optical Society of America*, January, 1944.

# The Influence of Strain Rate on Carbon-Molybdenum Steels*

By R. F. Miller, G. V. Smith and G. L. Kehl

HIGHER industrial working pressures and temperatures have increased the necessity for greater knowledge of the behaviour of metals under stress at elevated temperatures, and although tensile strength, yield strength, creep strength, etc., are determinable, less is known about the ductility of a metal under conditions involving creep and the nature and extent of its ultimate failure.

Strength and ductility at high temperatures have been studied at least since 1913, but in the present investigation, some of the variables in such determinations were eliminated and the effect studied of temperature, strain rate, and heat-treatment which lead to transgranular or intergranular failure.

The tests were carried out on pearlitic carbon-molybdenum steel at 850°, 1,000°, and 1,100° F., and also at 1,000° and 1,100° F. on the same steel previously spheroidised, so that it was structurally stable at 1,100° F. Stress-rupture tests were made on both pearlitic and spheroidised material at 1,100° F.

In both conditions the tensile strength decreased with decreasing strain rate, and was more pronounced at higher temperatures. With decreasing strain rate, the elongation increased to a maximum and then decreased, the latter coinciding with the appearance of intergranular failure. Reduction of area decreased continuously with decreasing strain rate.

Intergranular failure took place in both pearlitic and spheroidised material at slow rates of straining at 1,000° and 1,100° F., but at 850° F. the fracture of the pearlitic material was always transgranular. The elongation and reduction of area preceding fracture were appreciably greater for spheroidised than for pearlitic material. The transition from transgranular to intergranular failure occurred at a slower strain rate for the spheroidised than for the pearlitic material.

It was also found that surface oxidation on carbon-molybdenum steel may accelerate failure by reducing the effective cross-section whilst intergranular oxidation may also accelerate failure.

The authors conclude that the idea of brittleness attached to intergranular failure is inappropriate, as it may be preceded by appreciable deformation. Transgranular failure usually results from overheating or overstressing caused by diminution of cross-section due to corrosion, and hence to relatively rapid strain rates.

It follows, therefore, that under slow rates of straining at elevated temperatures, the normal failure of metals is through the grain boundaries, and that intergranular failure does not necessarily indicate deterioration of the metal or lack of plasticity preceding fracture. Even though considerable intergranular cracking may have occurred, the remaining sound metal may be no less ductile than it was originally, and may still withstand considerable bending or other rapid deformation.

Controlled strain rate tensile tests on pearlitic and spheroidised specimens are given in Table I.

(The manufacturers of carbon-molybdenum steel in the U.S.A. recommend its use up to temperatures of 1,050° F., and a large tonnage has been used at these and higher temperatures in oil-cracking still tubes and other applications.)

TABLE I.—CONTROLLED STRAIN RATE TESTS.

| Temperature, °C. | Strain Rate in In./Hour. | Tensile Strength, Tons per Sq. In. | Elongation, % | Reduction of Area, % | Duration of Test. | Hardness. | Type of Fracture. |
|---|---|---|---|---|---|---|---|
| A. Controlled Strain Rate Tensile Tests on Pearlitic Carbon Molybdenum Steels. | | | | | | | |
| 595 | 7·5 | 17·0 | 37·5 | 86·0 | 3·5 mins. | 194 | Transgranular |
| 595 | 0·1 | 12·5 | 51·0 | 62·5 | 5·1 hours | 176 | Intermediate |
| 595 | 0·001 | 6·4 | 40·0 | 55·0 | 393 hours | 115 | Intergranular |
| 540 | 7·5 | 20·4 | 37·0 | 84·5 | 3 mins. | 215 | Transgranular |
| 540 | 0·1 | 18·2 | 42·0 | 67·5 | 4·4 hours | 215 | Intermediate |
| 540 | 0·001 | 14·7 | 19·5 | 18·0 | 238 hours | 160 | Intergranular |
| 455 | 7·5 | 25·0 | 54·0 | 78·0 | 3 mins. | 222 | Transgranular |
| 455 | 0·1 | 24·5 | 33·5 | 77·5 | 3·6 hours | 232 | Transgranular |
| 455 | 0·001 | 22·8 | 10·0 | 66·0 | 426 hours | 244 | Transgranular |
| B. Controlled Strain Rate Tensile Tests on Spheroidised Carbon Molybdenum Steels. | | | | | | | |
| 595 | 7·5 | 12·0 | 66·0 | 86·0 | 6 mins. | 166 | Transgranular |
| 595 | 0·1 | 8·6 | 86·5 | 87·0 | 9 hours | 150 | Transgranular |
| 595 | 0·001 | 4·5 | 59·0 | 65·0 | 600 hours | 110 | Intergranular |
| 455 | 7·5 | 17·6 | 39·0 | 79·5 | 3·5 mins. | 196 | Transgranular |
| 455 | 0·1 | 15·4 | 70·0 | 83·0 | 7 hours | 188 | Transgranular |
| 455 | 0·001 | 10·0 | 78·0 | 62·0 | 780 hours | 130 | Intergranular |

*The influence of strain rate on strength and type of failure of carbon-molybdenum steel at 850°, 1,000°, and 1,100° F. *Am. Soc. Metals*, 31 (4), 1943, 817–845.

# Trends in Permanent Magnet Alloys

PERMANENT magnet materials which have relatively higher coercive force and higher residual induction, good machinability and use a minimum of critical materials have been developed in recent years. Their availability has greatly influenced the design of electrical indicating instruments, which have become sturdier and more reliable and of higher sensitivity. For the past 15 to 20 years, 36% cobalt steel permanent magnets have provided a means of producing higher sensitivities in instruments. The inherent high cost of this material limits its use primarily to the higher sensitivity instruments where the chrome and tungsten steels are unsatisfactory.

Recently, great advances have been made in permanent magnet materials by the development of the aluminium-nickel-cobalt iron (Alnico) alloys because of their even higher coercive force and available energy. These magnets are characterised in electrical instrument design by their relatively large cross-section and short length which produce a given flux across a given air gap ratio. They are highly resistant to demagnetising fields due to their high coercive force. Manufacture of Alnico materials may be carried out by either of two methods—the sintering process or casting, mostly the latter.

An even newer material and one containing less critical materials is Comol, whose typical composition is 12% cobalt, 17% molybdenum, and the balance iron. It comes closer to

From *The Iron Age*, March 30, 1944.

the specifications of an ideal magnet than any other material since it has high coercive force, residual induction, and available energy, besides having good machining and fabricating qualities. The alloy can be easily cast, and when properly heat-treated can readily be machined. With Comol, a coercive force of about 245 is obtained, compared with 210 for a 36% cobalt steel. Residual induction of 10,300 gausses is higher than either 36% cobalt steel or Alnico II. Comol has a maximum energy value of 1,100,000 ergs, as compared with 930,000 for 36% cobalt steel and 1,650,000 ergs for Alnico II.

## Measuring Corrosion Precisely

E. A. Gulbransen, of Westinghouse Laboratories, who devised the vacuum microbalance, has given some data on rust formation. The apparatus consists of a sensitive quartz balance operating in an all-glass vacuum system. Movements of the balance are observed on a scale micrometer microscope, and the sensitivity is better than 0·5 microgram with a sample of 0·7 gram. Weight-time curves can be obtained for the oxidation, degassing or hydrogen reduction of a metal sample over a wide range of temperature and pressure conditions. As an example, Gulbransen measured a film 30 angstroms thick that formed on high-purity iron at 25° C. As measured by the microbalance, corrosion of high-purity iron, stainless steel and copper in the air, and over a wide temperature range, starts rapidly and then decreases, finally corresponding to a parabolic law.

*Mining and Metallurgy*, March 1944.

# Cemented Carbide-tipped Milling Cutters

By Fred W. Lucht

ONE of the principal reasons for the long delay in the successful application of cemented carbides to the milling of steel has been primarily due to the fact that it was applied in exactly the same manner as it was applied to high-speed steel cutters in the past. It was found that rigidity of set-up, power, the proper cutting speed, and the proper tooth loading were of yet greater importance than with high-speed steel cutters. It was also found that the positive cutting angles which are used for high-speed steel cutters for milling steel were really fatal with cemented carbides, and slight progress was made until it was known how to apply cemented carbides properly to single-point tools for turning, facing, and boring interrupted cuts. This resulted in the use of the proper combination of positive and negative cutting angles and gave the first real clue to the successful application of cemented carbides to milling steel, because all milling cuts are interrupted cuts due to the nature of this type of machining operation.

In other words, the application of cemented carbides to milling cutters involves exactly the same basic principles as have been applied to single-point tools which take interrupted cuts. On all cutting tools the proper combination of the side-cutting edge angle (bevel angle on milling cutters), the back-rake angle (axial rake angle on milling cutters), and the side-rake angle (radial rake angle on milling cutters) has a direct bearing on tool life since these three angles control the amount of protection afforded the cutting edge and the nose radius or chamfer. The latter is usually the weakest portion of any cemented carbide cutting tool, and must receive maximum protection. It is doubly important to protect the nose radius because it also maintains the size on the cut.

A general requisite to be remembered in applying cemented carbide tools to interrupted cutting (milling) operations is to build up sufficient back pressure through the design of the cutting tool to prevent the tool from digging into the cut in any direction and also to absorb all back-lash in the machine before the nose radius or chamfer on the tool enters the cut. Failure to observe this simple consideration may be the cause of much unnecessary tool trouble.

### Operating Precautions

The following precautions should be observed when using cemented carbide-tipped cutters:—

1. Never disengage spindle while feed is engaged.

2. Always have the cutter rotating before feeding the work up to the cutter.

3. When using machines with rapid traverse make certain that the rapid traverse is out and the regular feed in before the work contacts the rotating cutter.

4. When stopping the machine, first throw out the feed and then immediately disengage the spindle clutch.

5. Never allow the cutter to idle in the cut, as the rubbing of the cutting edges against the work has a lapping effect on the cutting edges which dulls the cutter.

6. Keep the cutter rotating when returning the table to starting position after a roughing cut.

7. After a finish cut, the work should be removed before returning the table. When face-milling on a universal knee type of milling machine, the table must be set at zero position. The table should travel normal to the centre line of the cutter spindle, or be set to travel slightly past at an angle equivalent to 0·002 in 18 in., so that the trailing portion of the cutter will not spoil the work. When face-milling on a plain type milling machine of either the horizontal knee or the vertical type, the angular relation of the milling-machine spindle to the direction of table travel is such that the trailing portion of a cutter which is properly ground will not spoil the finish on the work. This also applies to the manufacturing and planer-type of milling machine. Chips always should be wiped from the ways before moving the table saddle or knee.

From *Mechanical Eng.*, **66**, March, 1944, 192–198.

## Platinum Minerals Identified in Alunite

By S. H. Cress and C. Feldman

IN the course of an examination of alunite, a basic sulphate of potassium and aluminum, from different deposits in the Western States now being made by the U.S. Geological Survey, traces of platinum metals have been identified. Alunite is generally considered a possible source of aluminium or potash or both. Platinum metals have not hitherto been identified in alunite, although they have been found in jarosite, a related iron sulphate mineral. In southern Nevada, palladium, platinum and gold were discovered in association with plumbojarosite, and argentojarosite has also been described.

From *Engineering and Mining Journal*, December 1943.

The platinum metals in alunite were first detected chemically and further identified spectrographically. A lens of schist in alunite from Arizona assayed 1 oz. per ton of platinum (28.7 gm./metric ton) with traces of palladium and rhodium. Another sample of alunite showed a trace of platinum. Alunite from Colorado yielded 1·4 oz. per ton (40·2 gm./metric ton) of silver and a trace of platinum. Another sample showed a trace of rhodium. The platinum metals are apparently present in an oxidised form, as no metallic flakes could be identified, and the metals were detected only on concentration by assaying or chemical treatment. Not enough determinations have been made as to the possible commercial extent of this source of the metals. Incidentally, the spectrograph has shown traces of rubidium in a few samples and traces of gallium in nearly all of the samples of alunite so far examined.

# Metallography with the Electron Microscope

By C. S. Barrett

THE techniques that have been most satisfactory, the difficulties encountered, the resolution obtained, and the peculiarities that have been noted in the microstructures in metallographic applications of the electron microscope made at the Carnegie Institute of Technology are discussed. About 1,200 exposures have been made with an RCA type B2 transmission electron microscope, and a number of these have been selected to illustrate the results obtained. In addition to comments on techniques and the quality of the photomicrographs obtainable with them, the nature of etch attack on a few metals and the possible relation revealed between the fine structure revealed by etching and the mosaic block structure of the grains are also considered.

In general, the microphotographs were from replicas of silica, deposited upon polystyrene and floated from the polystyrene in ethyl-bromide. The samples were mounted in bakelite, polished and etched, then the polished bakelite surface was given a very slight coat of beeswax in ethyl bromide and placed in a mounting press under powdered polystyrene. The press was heated to 150° C. before applying pressure, then cooled to 70° C. while under a constant pressure of 3,000 lb. per sq. in. The bakelite-polystyrene interface then cleaved apart very early exposing the moulded replica of the specimen surface, on which the silica was deposited from a tungsten conical filament in a small chamber evacuated by a small diffusion pump. Two photographs were also taken by the wet-stripping formvar method. The materials photographed are given in Table I, together with their compositions and thermal treatments. All photographs were taken at magnifications of 2,000 to 6,300 and subsequently enlarged.

The resolving power of a light microscope seldom exceeds 0·5 microns (5,000 Angstroms). The electron microscope using a wave-length 1/100,000 that of ordinary light and having a numerical aperture of about 0·02 instead of the usual 1·2 to 1·4 should have a theoretical resolving power some 1,500 times better. The best obtained so far, however, is 40Å, which is 100 times better than the optical microscope. Resolution in metallographic applications is limited by the details that can be developed by etching and transferred to a replica, and the present results indicate that two spots 150Å apart can be definitely resolved by the polystyrene-silica method and roughly the same distance by the formvar method.

The etched surface of single-phase metals and alloys frequently exhibit structures of remarkable interest. The attack of the etching solution appears to be fastest along the boundaries of domains, much smaller than grains, which in copper are rod-shaped, and in Monel Metal are equiaxed. The rod-shaped domains seen on the surface of deeply etched copper show that the rod axes are approximately parallel in an individual grain, or in a large part of a grain, as if paralleling a crystallographic axis. The rods are equiaxed in cross-section having diameters up to 0·1 to 0·5 microns and lengths up to 5 microns. Different etching solutions have given patterns of similar character and roughly similar dimensions, and the patterns are always irregular and do not provide evidence of a regular periodic imperfection in the latter that has sometimes been postulated.

The domains in Monel Metal are smaller than in copper and appear to be equiaxed blocks about 0·05 or 0·1 microns in size in the quenched material, and about 0·2 microns in the over-aged material. None were developed in the properly aged alloy, possibly because the etchant was controlled by the distribution of precipitate, which suggested that the pattern in over-aged Monel Metal is controlled by the precipitate rather than by a pattern of imperfections.

A large number of slip lines appear in polycrystalline samples of copper and Monel Metal, and the spacing of these lines are greater than the dimensions of the blocks revealed by etching. In Monel Metal there is a marked tendency for the lines in Monel Metal to be spaced 0·3 microns apart after a compression of a few per cent., while in copper that has received a similar amount of deformation by compression there was no

TABLE I.—COMPOSITIONS AND TREATMENTS.

| Material. | Composition, %. | Treatment. |
|---|---|---|
| High-speed steel | C 0·70, Mn 0·24, Si 0·29, W 17·8, Cr 4·05, V 1·04. | 845° C. for 20 mins., 1,290° C. for 2 mins. 45 secs., oil-quenched and tempered. |
| Copper | Oxygen-free high conductivity | Hot-rolled rod annealed 1 hour at 800° C. |
| Monel Metal | N 1·66, Cu 29, Fe 1, Al 2·75 | Annealed at 980° C. followed by various rates of cooling. |
| Tempered martensite | C 0·35, Ni 3·5, Cr 1·5 | 900° C., quenched water and tempered. |
| Spheroidized alloy steel | C 0·35, Ni 3·5, Cr 1·5 | 900° C., quenched water, tempered 480° C., spheroidised at 775° C. |
| Spheroidised carbon steel | C 0·60 | Spheroidised at 650° C. |

TABLE II.—THEORETICAL STRENGTH ESTIMATED FROM BLOCK SIZE.

| Material. | Block Size $d$, A. | Theoretical Yield Strength, Tons per Sq. In. | Observed Yield Strength, Tons per Sq. In. |
|---|---|---|---|
| Copper annealed | 3,000 | 4·9 | — |
| Copper compressed 75% | 1,000 | 14·7 | 15·2 (tensile) |
| K Monel, quenched | 1,000 | 21·0 | 22·3 |
| K Monel, aged | 500 | 42·4 | 53·5 |
| K Monel, over-aged | 2,000 | 15·2 | 44·6 |
| Pearlite, finest | 500 | 51·3 | 76·0 |
| Pearlite, mean interlamellar spacing | 1,100 | 23·2 | |

From *Metals Technology*, 1943, vol. 10, No. 6; and A.I.M.E., *Tech. Pub.*, No. 1637, p. 19.

preferred spacing between 0·3 and 2·5 microns. In the photomicrographs of the finest pearlite that could be produced in eutectoid plain carbon steel by a gradient quench the minimum interlamellar spacing that occurs with reasonable frequency is about 0·05 microns, and the non-lamellar areas have dimensions approximately the same. In the extremely finely dispersed precipitate causing age-hardening in Monel Metal, many of the particles are spaced no more than 0·03 microns apart and 0·05 microns spacings are common.

The equations of Orowan and W. L. Bragg are tested in the light of the observed slip-band spacings and block sizes. Assuming that the domains brought out by etching and the spacing between particles in the photomicrographs are the blocks that act as units, the tensile and yield strength calculated by Bragg's equation are compared with observed strength, Table II.

It was found difficult to obtain reproducible and trustworthy results with tempered martensite. By comparing the appearance of spheroidised steels with quenched and tempered steels polished and etched in the same manner some measure of confidence was obtained, although the differences between the structures were still greater than they should be, possibly due to variations in polishing or etching effects.

# Experiments in Stress-Relieving Castings and Welded Structures by Vibration

By R. T. McGoldrick and H. E. Saunders

EXPERIMENTAL methods undertaken in an attempt to expedite the stress-relieving and stabilising of welded steel and cast-iron structures by vibration and by a combination of vibration and annealing are described. In the application of these experimental processes, the part to be stress-relieved was machined or trimmed down as nearly as practicable to its finished size before the stress-relieving process was undertaken, as it was considered that some of the residual stresses, such as those in the skin of a casting, would be removed with the metal and that the remaining metal would yield more readily to the internal forces. The stresses in the vibrating operation were made as high as possible in order to produce the desired effect, but not so high as to damage the part unless a weak spot existed in it, and the vibrating operation and the frequency employed were selected to suit the particular part or structure.

In vibration experiments to stabilise high-test grey iron castings for chairs for a towing carriage, the castings, after rough machining and before annealing, were vibrated, jarred or bumped in a large moulding machine to accelerate the removal of all residual strain due to casting. Each casting was subjected to at least 25 definite heavy blows or vibrations or to vibration at high frequency for 1 min. The castings were then annealed at 540°–565° C. for 6 hours and cooled in the furnace at a rate not exceeding 540° C. in 48 hours. After cooling, the castings were again vibrated, jarred or bumped to remove residual strains. Castings subjected to this stabilising process were checked carefully at intervals for more than a year, without showing any measurable change in shape. A large surface plate weighing about 9,000 lb., and a large layout table weighing 6,150 lb., made in high-test grey iron, were also subjected to similar experiments.

Vibration experiments on welded structures were carried out on two large structural parts of a towing dynamometer and on the welded tubular structure of the towing carriage, all of which were too large for any available annealing furnace. The two structural parts consisted of a box-shaped girder and a floating beam designed with the precision of the chair castings and surface plates, and, like them, had to remain stable and true for long years of service. For stress-relieving operations on these parts, a vibration generator was specially developed and consisted essentially of two parallel shafts, motor-driven, geared together to run in opposite directions at the same speed and in opposite phase, and carrying eccentric weights on both ends.

On the welded structures, dynamic stress data were taken during the vibration operation only on the dynamometer fixed girder and on the floating beam, in order to furnish a safe guide in applying vibratory loads, and not for the purposes of stress-analysis. In view of the high resonance magnification involved, of the order of 30 or more, it might be considered that damage would occur in such a method of stress-relieving owing to accidental running through resonance. There is little danger of this, however, because the damping will increase rapidly as the average stresses approach the elastic limit. If the endurance limit is exceeded there is the possibility of fatigue failure, but this would occur only after a large number of stress cycles.

It was not practicable in any of the cases dealt with to measure the amount of stress relief actually obtained. Observations were made only on the general distortion of the structures after the various methods of stress-relieving were carried out. It was considered that, if parts or structures showed no large distortion, due to these processes, they would not distort in actual subsequent operations. In general, the process of vibrating parts and completed structures, which cannot be stress-relieved by annealing, may or may not relieve stresses, but it increases confidence in the stability of the parts so treated.

From *Journal Amer. Soc. Naval Engineers*, 1943, vol. 55, No. 4, pp. 591-609.

# Electrolytic Polishing of Metallographic Specimens

By L. A. Hauser

ELECTROLYTIC polishing of metallographic specimens of iron and steel, as well as non-ferrous metals, —i.e., anodic attack in a fluid electrolyte, has proved to be an extremely useful tool to the metallographer. The process is rapid and economical. The chief advantage is that it produces a smooth, scratch-free surface, with no disturbed metal. The structure observed under the microscope is the true structure, not one which may have been smeared or flowed, which is possible by even the most careful mechanical polishing.

Electrolytic polishing is not foolproof, and the operator must develop a technique for consistent results. However, operators lacking the skill required for good mechanical polishing can achieve excellent results with this method. Considerable time may be saved over the conventional method of polishing, particularly if large samples are to be polished, or if many samples of the same grade are to be polished.

From *The Iron Age*, January 20, 1944.

There are limitations to the electrolytic polishing process. On some specimens, the surface appears wavy at low magnifications, and, in general, structures are best revealed at magnifications of 500 diameters or higher. Some inclusions are held intact and appear in their true shape. They are not ground flat. However, many inclusions fall out, or cause localised attack and pitting, but usually at a relatively high magnification, areas free from pitting may be found for study or photography. In its present stage, electrolytic polishing is not recommended for the study of nonmetallic inclusions.

# Influence of Initial Structure and Rate of Heating in Carbon Steels and Iron-Carbon Alloy*

By T. G. Digges and S. J. Rosenburg.

IT was previously recognised that rate of heating through the transformation temperature range has a marked effect on austenitic grain size, and the present research was carried out in order to determine the effect of the initial structure (that existing prior to heating to the temperature producing the austenitic grain size), as well as that of the rate of heating.

The tests were carried out on a high-purity alloy of iron and carbon, and on two commercial plain carbon steels each containing 0·5% carbon and which differed from one another principally in the amounts of alumina and aluminium. The rate of heating of the specimens was raised either by plunging them into a lead bath or by heating them in a vacuum.

Although both initial structure and the rate of heating affect grain size at a particular temperature, it was found that rate of heating is the more important of these two variables. This was in fact anticipated since with slow rates of heating some spheroidisation of the initially lamellar structures occurred, and the austenite thus formed from partially or completely spheroidised structures. Such spheroidisation, however, could not have occurred during very rapid heating.

This heat effect on grain size was pronounced in the case of the iron-carbon alloy, small grains being produced with rapid heating at 1,475° and 1,600° F., and extremely coarse grains with slow heating, but variation of initial structure had no effect.

With the two steels, on the other hand, only slight differences in grain size with variations in both initial structure and rate of heating were obtained, and no definite correlation between initial structure and grain size was established.

The principal difference found was that the effect of rate of heating on grain size was reversed in the steels to that observed in the iron-carbon alloy in that the finest grain structure was produced in the steels with slow rates of heating, whilst as stated above, slow heating of the iron-carbon alloy produced the coarsest austenitic grain size.

*Trans. Amer. Soc. Metals*, **31** (4), Dec., 1943, 777–815.

# Zircon Refractories in Aluminium-Melting Furnaces

DESPITE the relatively low melting temperatures developed in them, aluminium-melting furnaces present a sizable refractories problem. High-heat-duty firebrick, super-duty and high-alumina refractories fail, even at operating temperatures as low as 1,220° to 1,300° F. (660° to 704° C.), because of penetration by metal, oxide or vapour, or a thermit reaction with iron oxides and silica, or mechanical abuse when charging and cleaning the hearth and side walls of the furnaces.

Over the past two years considerable successful experience has been recorded in the use of zircon refractories for the construction of the working hearth in reverberatory or open-hearth aluminium melting furnaces. Zircon (zirconium silicate) refractories have the peculiar property of not being "wet" by aluminium metal, dross or oxide. Their apparent specific gravity is 4·46, and thus spalls or small particles of brick will not float in the common aluminium alloys.

*Scientific American*, April, 1944.

# Rapid Determination of Iron, Copper and Silicon in Aluminium Alloys

METHODS involving the use of a special solvent, a fluoborate solution, have been proposed by Nikolaev for rapid determination of iron,[1] copper,[2] and silicon[3] in aluminium. The fluoborate solution is stated to activate the dissolution of the alloy in sulphuric acid, to bring the iron into solution in a stable ferrous state, suitable for titration with permanganate, and to leave the copper and silicon completely insoluble and unoxidised.

## Determination of Iron

*Reagents.*—Sulphuric acid, 10%. Dissolve 120 ml. of $H_2SO_4$ (sp. gr. 1·84) in 2,000 ml. of water, and add 0·02 N $KMnO_4$ to faint pink tinge.

Fluoborate solution. Dissolve 100 g. of KF, $2H_2O$ and 150 g. of $Na_2B_4O_7$, $10H_2O$ in 1,000 ml. of boiled water at 80–90°. Filter while hot. Add to the solution 50 ml. of $H_2SO_4$ (sp. gr. 1·84) and drop in 0·02 N $KMnO_4$ to faint pink colour (5–8 drops). The solution is used hot. If, on cooling, crystals (a mixture of boric acid and borofluoride) separate, shake up the mixture, remove a part, and warm to dissolve the crystals.

*Method.*—Weigh out 2–0·25 g. of sample into a conical flask (300 ml.). Add 50 ml. of the fluoborate solution and 50 ml. of 10% $H_2SO_4$. Cover the neck of the flask and place on an air-bath. According to the state of division of the sample the time for solution varies from 20 mins. to 1 hour. If the solution is cloudy, filter and wash with 20–30 ml. of 10% $H_2SO_4$. Leave the solution to cool, and add 0·1–0·2 g. magnesium powder (with iron content not higher than 0·03%). Shake the magnesium round in the solution, so that the bubbles of hydrogen that are released permeate the whole mass of the solution, but take care that no particles of magnesium are left on the side of the flask. After 5 mins. titrate with 0·02 N $KMnO_4$.

*Notes.*—If the insoluble matter sinks to the bottom of the flask and the solution is colourless, then with silicon

1 N. S. Nikolaev. *Zavod. Lab.*, 1941, **10**, 205–207.
2 N. S. Nikolaev. *ibid.*, 473–474.
3 N. S. Nikolaev. *ibid.*, 536–538.
4 Muller and Kopps. *Z. anorg. Chem.*, 1910, **68**, 160.
Abstracted by G. S. Smith, May 21, 1944.

contents up to 3% and copper contents 1–5%, it is possible to titrate in the presence of the precipitate.

Copper is left insoluble, both during solution and during titration with $KMnO_4$ (in cases where it is not removed by filtration).

The weight of sample taken should be such that in 100 ml. of the solution prepared for titration there should be not more than 50 mg. of MnO. This corresponds with 12 ml. of 0·02 N $KMnO_4$. Mn is easily oxidised by $KMnO_4$ in the presence of fluorine ions.[4]

### Determination of Copper

The insoluble matter containing the copper is treated with nitric acid to dissolve the copper, the solution filtered from silicon, the nitric acid removed by evaporation with sulphuric acid (the original paper does not give further details for these operations) and the copper titrated by means of thiosulphate using an iodo-bromothiocyanate reagent of the composition —35 g. KCNS, 20 g. KBr and 6 g. KI in 1,000 ml. water—25 ml. of which are sufficient for titrating copper present in the usual quantities in aluminium alloys when 0·5 g. of sample is taken.

### Determination of Silicon

When the sample is dissolved as described for the iron determination silicon is left insoluble as free silicon. The presence of boric acid prevents the formation of $SiF_4$ and oxidation to $SiO_2$ does not occur.

The insoluble copper and silicon is collected on a Gooch crucible, and after washing is treated with a warm mixture of three parts by weight of pure alcohol and one part of $HNO_3$ (sp. gr. 1·38). The dissolved copper is washed through and the residue of silicon washed with sulphuric acid and alcohol and weighed after drying.

The mean variation of results from those obtained by the control method is given as ± 0·7%, but it is claimed to be superior in repeatability to the control method—acid attack and soda fusion. The alcohol used with the nitric acid for dissolving out the copper is stated to reduce the oxidising action of nitric acid, so that it is incapable of oxidising any silicon.

# Evaluating Steel Forgeability

By C. L. Clark

DATA are meagre on the properties of steels at elevated temperatures, and yet information of this type is of considerable value in establishing the various hot-forming operations like forging. Various tests have been used in the past for determining the proper forging temperatures with varying degrees of success. Recent laboratory work, however, indicates that a definite relationship exists between hot twisting characteristics and forging temperature. This test is believed to be more sensitive, and the results more quantitative than those obtained from other methods of evaluation.

The apparatus used consists of a furnace for heating and maintaining the specimen at the given temperature, a variable speed motor for turning the specimen at the desired rate, a chuck mounted in a bearing to which the torque arm is attached, and a platform scales for measuring the force produced during the twisting of the specimen. The specimen is fastened in the chuck of the variable speed motor and is rotated while it is being heated to and held at the desired temperature, and after 15 mins. at temperature the motor is stopped, the other chuck tightened, and the motor restarted at the desired speed. A counter, which automatically starts and stops at the beginning and end of the test, gives the number of revolutions while the force exerted on the scale is read and recorded. The scale reading, multiplied by the length of the lever arm, gives the torque, expressed in in.-lb.

Work has been done on different specimen sizes, with steel in varying conditions of initial heat-treatment, and at various rates of twist, but for convenience the specimen size has been standardised at $\frac{5}{8}$ in. diameter, with the material in the hot-rolled condition, since at temperatures of 1,800° to 2,500° F. the initial heat-treatment has little if any influence on the results obtained. For forging applications a rate of twist of 180 r.p.m. is used, which is the lowest operating speed of the motor.

ANALYSES OF STEELS TESTED.

| Type. | C. | Mn. | Si. | P. | S. | Cr. | Ni. | Mo. |
|---|---|---|---|---|---|---|---|---|
| 4615 | 0·14 | 0·62 | 0·30 | 0·022 | 0·021 | 0·15 | 1·72 | 0·25 |
| 2512 | 0·10 | 0·56 | 0·28 | 0·018 | 0·020 | 0·15 | 5·01 | 0·05 |
| 10105 | 1·02 | 0·31 | 0·35 | 0·015 | 0·018 | 0·30 | 0·09 | 0·03 |
| 18–8 | 0·05 | 0·52 | 0·52 | 0·006 | 0·012 | 17·78 | 9·60 | — |

Results obtained from four different steels, two of which are of the constructional type, one a tool steel and the other a stainless grade, with compositions referred to in the accompanying table, are given in Figs. 1 and 2.

**Fig. 1.—Hot working characteristics of 4615, 2512, 10105, and 18–8 steels, as determined by hot twist tests.**

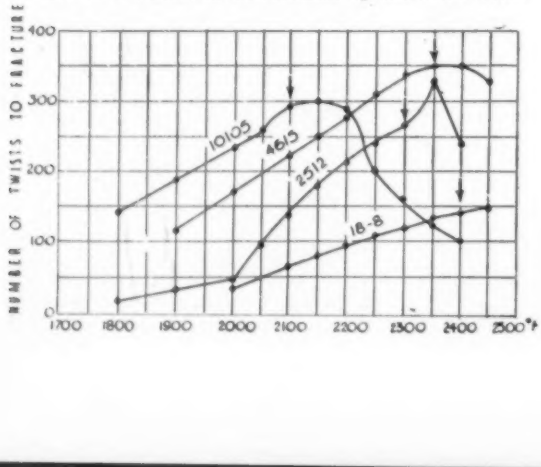
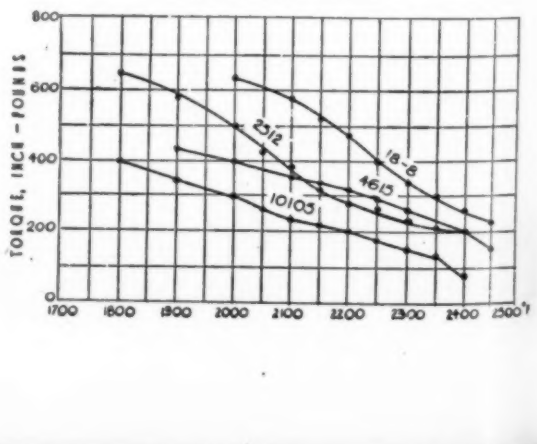



**Fig. 2.—The torque curves obtained for the various steels tested.**



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In each case the number of twists required for fracture increases as the temperature is raised until a critical temperature is reached, after which the number of twists decreases. There are, however, differences between the steels in (*a*) the number of twists required for fracture at a given temperature; (*b*) the rate at which the number of required twists increases with temperature; (*c*) the temperature at which the number of twists reaches a maximum; and (*d*) the rate of decrease in the number of required twists after the critical temperature is passed.

The torque curves show the strength to decrease continuously as the temperature is increased, and thus the relationship is different from that found in the twist curve. With different steels, however, there are differences in the magnitude of the torque at any given temperature, and also in the rate at which the torque decreases with increasing temperatures. The stainless 18-8 has the highest strength at each of the temperatures considered.

The critical temperature obtained from twist tests on these steels was found to coincide exactly with the maximum forging temperature established through trial and error. The survey was extended to other types of steels, and the same definite relation ship was found to exist.

A metallographic examination of the fractured specimens revealed that as the critical forging temperature is exceeded, the nature of the failure changes in that intergranular cracking appears, even in sections removed from the actual fracture. The degree of this intergranular cracking increases the higher the testing temperature is above the critical temperature, and this accounts for the resulting decrease in the number of twists. Similarly, the rate of decrease in the required number of twists is a function of the susceptibility of the steel to intergranular cracking.

It has long been recognised that the deformation characteristics and path of fracture in steels is a function of temperature and rate of application of stress. At room temperature the deformation of all steels occurs primarily in the grains proper, and the path of fracture is transcrystalline. On the other hand, at 1,000° F. and under very slow rates of deformation, such as occur in creep or prolonged stress-rupture tests, the path of fracture in the low-alloyed steels under simple tension is largely intergranular.

While deformation rate is an important factor, it seems to lose its effect after a certain rate has been exceeded. For example, tests conducted on certain steels under rates of twist varying from 180 to 600 r.p.m., showed the temperature of maximum twist to be nearly constant for a given steel. The speed did, however, have an influence on the total number of twists required for fracture.

Results from hot twist tests indicate that such tests are sufficiently sensitive to reveal: (*a*) The temperature which must not be exceeded in the forging operation; (*b*) the change in ductility of the steel with varying temperatures; and (*c*) the change with temperature of the force required to deform the steel.

From *The Iron Age*, Mar. 16, 1944.

# The Centrifugal Casting of Gear Wheels

CENTRIFUGAL castings made of steel, cast iron and some other metals are generally stronger than those obtained by the normal process. In addition, there is less wastage of materials, and the mould is simplified, thus reducing cost in mass production.

The process was originally applied to tubes. Cylinder liners, valve seats and brake drums soon followed, and during the last few years centrifugally cast steel gearwheels have received wide application. Some of the steel dies employed for this purpose with vertical axis of rotation are illustrated, suitable for either single or stepped gears.

The steel die is generally made in two parts, the lower part being rigidly attached to the rotor, whilst the removable upper portion is held in position by a system of pivoted levers which lock under centrifugal action. Before closing the die, a sand core is inserted in the lower part which produces the necessary recesses in the gearwheel and also protects the die from the impact of the molten steel. It should be noted that the external portions of the wheel must be in direct contact with the steel die. Similar inserts in a complicated die are illustrated in the original. A composite unit of 18 dies of this type will produce nine stepped gears per minute.

Centrifugally cast gears have the same strength and behave in practice just as forged gearwheels.

From *Z.V.D.I.*, vol. 88, No. 7-8, Feb. 19, 1944. By courtesy of R.T.P. 3, Ministry of Aircraft Production

# Thermal Analysis of Clay Minerals and Acid Extraction of Alumina

THE U.S. Bureau of Mines has published a research report on the thermal analysis of clay minerals and acid extraction of alumina from clays for aluminium. The report presents preliminary results of a co-operative investigation by Bureau engineers and personnel of the University of Washington College of Mines, Seattle, Washington. Started a number of years ago, the joint experiments dealt with the high-alumina clay deposits of the West, and attention was confined chiefly to processes based on the use of sulphuric acid or sulphates.

The common clay minerals of major importance are classified as kaolinite, illite, and montmorillonite, and tests indicate that alumina can be extracted completely from certain minerals only—namely, those of the kaolinite type. Thus, determination of the mineral composition of a clay sample is of primary importance in the use of acid extraction methods. The characteristics of the various clay minerals are described, the test materials and methods employed in the treatment of the clay samples are discussed, as well as the effect of some variables on extraction of alumina, such as digestion under pressure and quartz admixture.

U.S. Department of the Interior Information Service, February 3, 1944.

# Cleaning Sheet Metal to be Spot-Welded

THE highly scientific mind of the chemist is augmenting the inventive genius of the tool equipment designer in speeding the production of warplanes.

An example is given in the announcement by the Vega Aircraft Corporation that the simple but ingenious substitution of phosphoric and chromic acid for the commonly used hydrofluoric acid in the cleaning of sheet metal to be spot-welded has resulted in a cleaner, brighter surface.

A further advantage of the new solution is that the sheet metal may be left in the tank from an average of three to five minutes up to half an hour without injuring the metal. Under the old method, immersion in the acid had to be timed almost to the second.

From *Flying and Industrial Aviation* (U.S.A.), 1943, **32**, 90. Digest by courtesy of R.T.P.3, Ministry of Aircraft Production.